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Ship Integration of Energy Scavenging Technology for Sea Base Operations

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14. ABSTRACT
Offshore renewable energy scavenging methods have become a major area of research in recent years. The U.S. Navy is especially interested in the ocean potential to provide clean energy and fresh water from sources like wind, wave, solar, current, and biological resources. It is important for the Navy to consider the integration of energy collection technologies into a mobile resupply platform. This scavenging ship will reduce the need for costly energy transport from shore to ship, reduce the carbon footprint made by naval sustainment, and provide fresh water and energy in cases of disaster relief.

Solar, wind and wave energy are the three sources that have been found to be most reliable and abundant for energy scavenging on ships. This investigation will provide background information about energy scavenging methods and energy potential for different locations around the world and different existing shipboard systems. This information can be used for future preliminary design of an energy scavenging ship.

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Abstract

Offshore renewable energy scavenging methods have become a major area of research in recent years. The U.S. Navy is especially interested in the ocean potential to provide clean energy and fresh water from sources like wind, wave, solar, ocean current, and biological resources. It is important for the Navy to consider the integration of energy collection technologies into a mobile resupply platform. This energy scavenging ship can potentially reduce the need for costly energy transport from shore to ship, reduce the carbon footprint associated with naval sustainment, and provide fresh water and energy in cases of disaster relief.

Solar, wave and wind energy have been found to be most reliable and abundant for offshore energy scavenging on ships. This investigation will provide background information about energy scavenging methods and energy potential for different locations around the world and different existing shipboard systems. This information can be used for future preliminary design of an energy scavenging ship.

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Executive Summary

A Sea Base Energy Scavenger can be defined as a platform capable of harvesting energy from renewable sources within the Sea Base. The Sea Base Energy Scavenger will be able to capture, store, and distribute energy to support seabasing operations. However, the concept of an energy scavenging ship is very new. Therefore, the design tools and assumptions had to be developed and tested before a ship could be envisioned.

The study began with background research on the different sources of ocean energy available. Next, seven locations in tropic and temperate regions were chosen for ocean data collection and analysis. The chosen locations were based on available data and level of Navy operation. The data was obtained from the National Oceanographic and Atmospheric Administration (NOAA) buoys. The raw data included wind speed, ocean current speed, solar radiation, wave heights, and depth temperature differentials. The sources of renewable energies studied were solar, wind, wave, biological, ocean current, and ocean thermal. Methods and technology of harvesting energy for each type of energy were researched and evaluated for ship integration.

After performing background research and analyzing source data, a matrix was created to evaluate methods for reliability, feasibility, cost, research and development and environmental effects. In the matrix, the different energy sources were compared on the same scale to determine their integration feasibility. Solar, wave, and wind energy were deemed most reliable and suitable for ship integration in a Sea Base Energy Scavenger.

58 Navy and civilian ships were analyzed to investigate compatibility with technologies and energy production. Monohulls, catamarans, SWATH's, trimarans, and quadramarans were included in the study to find the best ship configuration for a Sea Base Energy Scavenger. An interactive energy capture potential spreadsheet was constructed to calculate each ship's energy production potential using solar and wind technology. Wave technology was not included in the spreadsheet because the systems are still in development. Wave energy converters are difficult to scale because the existing prototypes are still in the proof of concept stage. The prototypes are designed for a particular costal area and wave climate to maximize efficiency. There is not enough data to make educated output predictions of wave energy collection systems in the seven regions worldwide. The spreadsheet was designed to ultimately determine a particular hull form, hull material, and deck arrangement for maximum energy collection and future concept design of an energy scavenging ship.

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1.0 Introduction

Original Mission Statement

The goal of this project was to design a Sea Base Energy Scavenger offshore platform to provide the capability to convert energy from environmentally sustainable and reliable sources. This platform system includes the ship integration method for harvesting, storing and distributing energy and fresh water.

Original Requirements

The Sea Base scavenger must:

a. be towed or sail independently of other vessels
b. deploy into energy collecting modes without external assistance
c. collect energy from renewable sources
d. store energy in an appropriate form
e. dock, moor or berth unmanned vehicles
f. distribute energy to unmanned vehicles
g. survive in conditions up to Sea State 8 and operate in Sea State 4
h. operate in temperate and tropical conditions

Redefined Mission Statement

The scope of the project was judged to be too extensive to be completed in the time allotted. The scope was redefined to provide recommendations of reliable harvesting methods applicable for ship integration. In choosing harvesting methods, energy output ranges are specified for different ship sizes and hull forms in the form of an energy capture potential spreadsheet. This spreadsheet was used to assess the feasibility of energy scavenging systems on Navy and civilian ships.

Methodology

To successfully design a Sea Base Energy Scavenger that harvests renewable energy, background research and preliminary data analysis of ocean energy potential was performed. Locations around the world were first selected to utilize historical oceanographic data. This data was then analyzed and graphed to find reliable energy trends. Renewable energy harvesting methods were also researched to provide a better understanding of how different scavenging systems work. Of the six methods researched, three were chosen for ship integration based on an evaluation and assessment matrix. These methods were further researched to learn more about technological advancements in those fields. Finally, multiple ship types were selected for technology to assess scaling and energy collection capabilities.

Subsequent to completion of the study, a preliminary exploration of the integration of study results in a ship concept was undertaken by on of the team members. Slides from that effort are in Appendix E.

2.0 Renewable Energy Technology

The following sections characterize each type of renewable energy that can be harvested in a Sea Base. They include biological, ocean current, ocean thermal, solar, wave, and wind energy. Most of these energy sources convert energy to the form of electricity. This electricity can be used in a number of applications that are not discussed in this study.

Biological energy uses algae to yield products like biodiesel and bio-hydrogen. Harvesting energy from algae is new to the energy industry. The only commercial scale algae farms are located on land in open ponds. Ocean current sources have potential to provide energy but require durable structures that are able to withstand drag forces in the water. Maintenance of the submerged moving components of a current turbine make it more difficult for offshore energy scavenging. Ocean Thermal Energy Conversion uses temperature differences at ocean depths to convert energy. This system has been commercially made and proven to produce large amounts of energy, however, it requires a total ship operation to function properly. Solar energy is a very developed industry that is continuously being improved. Present technology uses silicon solar panels, however, future technology utilizes systems made with less material or nanoantennas that increase efficiency. Wave energy technology includes many different systems that have been tested as prototypes. More data is needed to scale up to commercial ship integration. Lastly, wind turbines are a promising method of harvesting energy. Horizontal axis wind turbines are currently the most developed technology but future technologies include vertical axis wind turbines, flying electric generators and magnetically levitated turbines. The future technologies, however, are not as mature as horizontal axis wind turbines. They do not have enough data or are still only concept designs that have not been tested.

Biological

Due to the rising oil prices and the world food crisis, algae fuels have become a more popular means of producing biofuels. Harvesting algae is an attractive method of producing energy because of its many types of products, ease of production, and minimal effect on the environment. Algae produce biodiesel, bioethanol, bio-hydrogen, and biomass, which are less harmful to the environment. Algae can be harvested in both ocean and wastewater so it does not affect freshwater organisms.[12]

Algal fuels are the biological equivalent of solar panels in harvesting solar energy. Energy production from algae is through the photosynthesis process. The inputs of photosynthesis are carbon dioxide (CO_2) and visible light and the outputs are starch (biomass), oxygen (O_2), and hydrogen (H_2). Algae are especially valued because it can curb carbon dioxide levels in the atmosphere. Algae energy conversion efficiency depends on the photosynthetic efficiency. This is the amount of sunlight that is actually converted to chemical energy in the form of biomass. The minimum and maximum efficiency for photon conversion is 3% and 11%, respectively.[31] This range is dependent on the sunlight available and the nutrient levels of the environment provided for the algae. Conversion losses are caused by algae cells only absorbing light with wavelengths ranging from 400-700nm and the fixation of one CO_2 molecule in photosynthesis uses only 25% of the absorbed light.[32]

Biodiesel

One product of algae energy production is biodiesel fuel. Algae strains have high contents of oil and fatty acids, found mostly in their cell walls. Processing equipment is used to extract and convert oil from algae. Through transesterification, fatty acids are converted to methylesters, which can be used as diesel fuel. Algae cells are a good source for diesel fuels because it can grow 20-30 times faster than other food crops that are oil and fatty acid based.[4]

Current Technology

Harvesting algae for biodiesel production can be done in two different types of systems: open pond and closed loop systems. Open pond systems allow algae to grow in hot sunny ponds on land. This method is the least invasive method and can be easily extended to commercial use given enough open land is provided. The disadvantage of this system is that algae cells used must be resilient as they are vulnerable to viral infections and contamination from the surrounding environment. Also, the water used in the ponds must be maintained at a certain temperature for the most efficient algae growth, which is difficult to control with a large pond.[31]

Closed loop systems allow algae to grow in sealed containers, either in the form of clear bags or plastic tubes. These containers use water that is recycled and reused and have controlled levels of CO_2, pH, and temperature. They can be easily constructed and positioned so that algae organisms will be exposed to sufficient amounts of sunlight. Plastic tube photobioreactors, seen in Figure 1, can range from 25 to 100 meters long and have a diameter of 3-10 centimeters. Flat panel photobioreactors are a new advancement in harvesting algae. Although they are expensive, they use a smaller optical path, which allows more sunlight to reach more algae organisms.[32] Closed loop systems are very new to commercial scale energy production and require large amounts of expensive hardware and processing equipment for large scale implementation. The large, extensive equipment requirement and strict nutrient level controls make photobioreactors and harvesting algae a difficult method to integrate into a ship.

Figure 1. Tubular photobioreators [32]

Bio-Hydrogen

Algae can also produce hydrogen in its purest form (H_2), providing a product of photosynthesis that does not have to be modified to be used for energy. H_2 is produced in the absence of sulfur and oxygen in the medium, because it triggers a mechanism to stop producing oxygen and produces hydrogen instead.[12] Hydrogen cannot be produced if there are high levels of O_2 or sulfur present.

Present Technology

The most common way to harvest algae for H_2 production is through a two phase bioreactor system. The first phase is the photosynthetic growth phase, where algae cells grow aerobically in light and CO_2. The second phase is the H_2 production phase where sulfur and oxygen levels are depleted and H_2 is produced after 24 hours. The advantages to using this system is that it has lower production cost and improves H_2 purity. One disadvantage is that the photon conversion efficiency is lower due to the extensive processing.

The other system used is a one phase bioreactor system, where a specific strain of algae (Stm6) is used due to its high O_2 consumption and ability to induce H_2 production.[12] This processing system is simpler and less extensive because the algae are not put through two phases. The only major requirement is that the O_2 levels are low enough so that H_2 can be produced.

Future Technology

Algae energy production on a commercial scale is not as developed as other harvesting methods. Most algae production is done on a lab scale in research. Commercial implementation can be developed by finding ways to maximize sunlight exposure and finding cheaper ways to process algae. It is also difficult to control CO_2 and O_2 levels in algae production on a commercial scale.[31]

Future research needs to be done for more reliable hydrogen production on a large enough scale for ship practicality. The closed harvesting and processing system for hydrogen production requires control of nutrient levels. New strains of mutant microalgae, like *Chlamydomonas reinhardtii*, can be used because they have a high starch content that can induce increased H_2 production.[12] Advancements in developing large scale processing systems and finding ways for more efficient H_2 production can eventually lead to the use of algal hydrogen production on a commercial scale.

Ocean Current

Currents offer an excellent opportunity to extract energy with an estimated 5,000 GW of current power potentially available worldwide. Currently, turbines with fixed moorings, cable moorings, open wind mill design, vertical/horizontal axis turbines, and venturi ducts are used to produce electrical energy. Ocean currents provide a predictable and fairly constant unidirectional source of energy that is not affected by rapid changes in weather. Because water is denser than air, currents are a more energy dense source than wind. However, the submerged, moving systems will require durable structures to withstand the large drag forces and corrosion. These current systems will be more difficult to deploy due to the bulkiness of the equipment and turbines. Ocean current technology also requires an extensive deadweight mooring system. The deployment and retrieval of this system will complicate ship integration. Maintenance of the submerged, spinning components will require either retrieval or a specialized dive team. The systems are massive in size. Ocean turbines typically have a diameter of forty meters or more. The overall efficiency of ocean current technology is 37%. This efficiency is a compromise between allowing water to flow past the turbine and stopping the ocean current.[24]

Due to the difficulty of maintaining turbines underwater, ocean current harvesting technologies were problematic for ship integration. This method requires permanent mooring to a structure or ocean floor, which makes it difficult to implement in a moving Sea Base. Further research was not done because ocean current turbines did not seem feasible for ship integration.

Ocean Thermal Energy Conversion

Ocean Thermal Energy Conversion (OTEC) is a thermal energy technology that converts ocean temperature differentials into electrical energy.[34] Temperature differentials are relatively consistent because heat absorbed from the sun at various ocean levels stays constant, making OTEC a reliable system.[3]

There are two types of OTEC systems: open-cycle systems and closed-cycle systems.[3] Both systems use temperature differentials to evaporate and condense an operating fluid. An open-cycle system uses seawater as the operating fluid. Sea surface temperatures generally range from 21° to 23°C in temperate and tropical regions. The warm water collected from the sea surface is de-aerated before entering a flash evaporator. From there, a fraction of the seawater is turned into low pressure steam.[3] The steam powers a turbine and creates power. Cold water is pumped from a depth of 1,000 m using a cold water pipe with a 2-3m diameter. The cold water condenses the surface water vapor back to a liquid state before it is released back into the ocean. In an OTEC system, energy production is directly related to the magnitude of the temperature differential. Greater temperature differentials produce more desirable efficiencies. The cycle continues with little or no wasteful byproduct. Freshwater can be a positive byproduct of an open-cycled OTEC system with the evaporation of seawater removing salt and unwanted particles. However, the open system is not commonly used because of the corrosiveness of seawater.

In a closed-cycle system, the working fluid is contained and continuously cycled through the system. The fluid starts as a cold liquid in the condenser. It is then pumped to an evaporator. In the evaporator, the surrounding warm surface waters heat the fluid to its evaporation temperature. The vapor then spins a turbine linked to an electric generator. After passing through the turbine, the fluid is sent back to the condenser to restart the process. The most attractive working fluids for closed-cycle OTEC include ammonia, methanol, propane, and Freon R-22.[3] Ammonia, especially, is a favored working fluid because of its low boiling point at −33.34 °C and its compatibility with the heat exchanger and turbine materials.

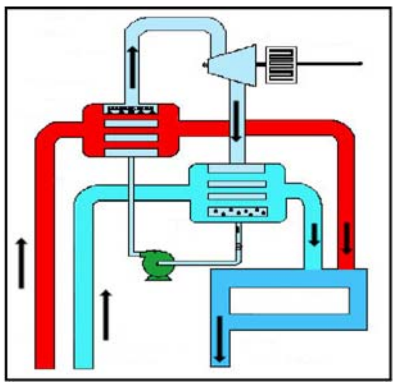

Figure 2. A closed-cycle OTEC system [20]

Overall usable power efficiency of an OTEC plant is about 2.7%. An OTEC plant needs 650,000 ft^2 (60,000 m^2) of total heat transfer area to produce 10 MW.[3] OTEC systems usually consume about 33% of the power they produce.

Present Technology

Current OTEC systems produce megawatts of energy, but have space requirements that fill entire ships. In 1979, the Natural Energy Laboratory of Hawaii Authority (NELHA) successfully converted a Navy barge into a 50 kW closed cycle OTEC system.[20] 40kW of the gross power was used to pump water through a 0.61 m diameter pipe at 2,700 gallons/min leaving 10 kW left for usable power. In 1981, the OTEC-1 successfully operated at 1 MW in Hawaii deploying a 670 m cold water pipe transferring power through underwater cables. Figure 3 depicts a schematic of OTEC-1.

OTEC plants also have the ability to run for up to thirty years at a time with no major maintenance to the main components. It operates similar to the common commercial refrigerating system in reverse like a heat pump.[3] However, cold water pipes do pose a major problem for operations and maintenance dealing with the corrosive nature and dynamic loads of the ocean over long periods of time when generating the required large flow-rates to the ship.

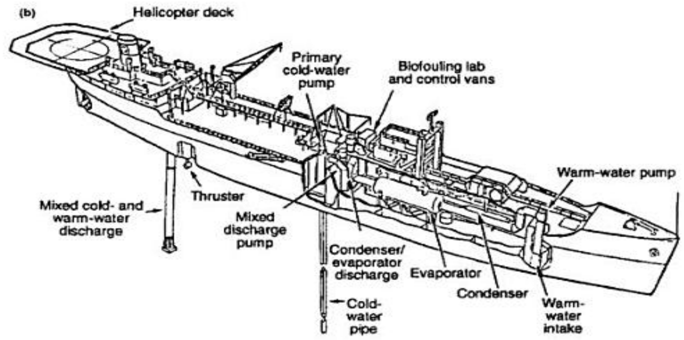

Figure 3. A model of OTEC-1 in Hawaii [3]

Future Technology

Interest in OTEC plants and projects exploded in the 1970's and 1980's, but has since died down due to the drop in oil prices from all time highs in the 1970's. Because of this, not much development has been noted in the OTEC field although this could change if oil prices increase along with other factors. Development of energy storage options can vary for OTEC systems with options ranging from electrolysis to ammonia tanks and methanol fuel. One major drawback is that the system operates best with a temperature differential of 22.2°C.[3] This only exists consistently between the latitudes of 15°N and 15°S, excluding many locations that the Energy Scavenger would operate. This sole reason explains why most development of OTEC systems occurs in areas near the equator.

Solar

Solar energy from the sun's radiation has been utilized and developed as a reliable source for renewable energy. Sunlight is converted to energy that can be used in the form of heat or electricity.

The overall average efficiency for solar radiation conversion to electricity by using photovoltaic cells is 20%.[36] One source of energy loss is the internal resistance from the transfer of electrons from one side of the cell to the other side when a current is induced. Also, a large part of the sun's energy is lost because photovoltaic cells can only utilize the light in the visible light spectrum. Maintaining this efficiency will likely be challenging in a marine environment due to the presence of a salt spray.

Present Technology

There are many ways to harvest solar energy. For the purposes of ship integration, photovoltaic cells were researched in detail. Solar panels made of photovoltaic cells use light photons to excite electrons in semiconductor material which creates a current that is stored in a battery or transferred to a grid. Photovoltaic cells are easy to sustain and deploy from a ship perspective because they have no moving parts. Disadvantages to photovoltaic cells are that they can only utilize direct visible light. Overcast or cloudiness can easily decrease the efficiency of the photovoltaic cells.

Future Applications

Nanoantennas

Future technologies for solar energy focus on finding ways to harvest the sun's radiation with higher efficiencies. Researchers at the Idaho National Laboratory have developed ways to use nanoantennas to capture not only visible light, but also infrared light. These nanoantennas are capable of capturing energy after sunset, because infrared heat is absorbed by the earth during the day and released later during the night. This technology is able to increase the efficiency of photovoltaic cells up to 80%.[18] Nanoantennas can be produced in thin sheets like foil or plastic wrap. The one drawback with this advancement is that the antennas create an oscillating alternating current that is too fast for direct current conversion for electrical application. Finding ways to slow down the cycle or convert the high frequency alternating current into a direct current will allow these nanoantennas to successfully store or transmit electricity for usage.

Solar Concentrators

Solar concentrators are used to focus the sun light on a photovoltaic cell. By concentrating the sunlight at the focal point in a solar collector, more light can be converted to electricity for less solar cell material. Solar concentrators come in the form of a dyed fiber optic glass that can be placed on top of a solar panel or a solar bubble made from cheap material. The solar bubble, patented by the company CoolEarth Solar, is a 2m diameter bubble that is able to produce up to 500kW, shown in Figure 4. This concentrator technology generates 300-400 times more electricity than a cell without a concentrator.[8] These bubbles are made with an aluminum reflective layer and a common plastic (polyethylene terephthalate) cover that is filled with air. One photovoltaic cell is held in place at the focal point of the concentrator where all the sunlight is focused. Because more sunlight is captured by one cell, the energy conversion efficiency is higher. This solar concentrator system is held together in a rigid support system. This support system is designed so that the solar bubbles will be able to withstand harsh weather conditions, like snow, rain, and winds up to 125 miles per hour.[8]

Figure 4. CoolEarth Solar Bubble [8]

Thin Film Solar Panel

Thin film solar panels are the newest commercially produced solar product. These panels are cheaper than traditional panels because they are easier to manufacture and are made with less silicon. These photovoltaic cells are made with silicon alloys like amorphous silicon or amorphous silicon germanium. Thin film solar panels are lightweight and flexible which make them optimal for ship integration. However, the efficiency of these panels is 12.5%, less than the efficiency of traditional solar panels.[35] They can be encapsulated in UV stabilized containers or backed onto materials that range from fabric to metal to fiberglass. Their containers depend on the environmental application. The performance of all solar technologies will be greatly enhanced by development of technologies and practical maintenance procedures to address marine environment effects such as the accumulation and residue from salt sprays.

Wave Energy Technology

A number of technologies have been advanced to harvest wave energy. Small scale prototypes have been built and have demonstrated high energy output levels. Wave generators often use the oscillating wave system at the surface of the water to collect energy. These oscillating systems consist of corrosion free components and solid mooring to a structure or the ocean floor. There are two types of wave energy scavenging systems: line absorbers and point absorbers. Line absorbers are generators that are typically the size of the average wavelength. Point absorbers are similar structures, but are smaller than the average wavelength.[9]

Wave energy scavengers can vary in operation and efficiency. Monoplane turbines have a maximum efficiency of 60%, or 70% with guide vanes similar to contra-rotating turbines. While sources of other types of wave energy scavengers were not provided, a safe judgment was taken into account for determining the overall efficiency of these wave systems. Minor losses such as idling and corrosion help show that a conservative efficiency of 40% should be used for wave power systems.[5]

Present Technology

Pelamis Wave Energy Converter

The Pelamis Wave Energy Converter, designed by Pelamis Wave Power Ltd., was the first commercial scale offshore wave energy converter to provide electricity to a national grid. It is a floating line absorber which uses four articulating tubular sections with hydraulic rams to extract energy as the wave passes below. The tubular sections are arranged in a line with hydraulic rams and electrical generators between each section. A rendering of the Pelamis system can be seen in Figure 5. Energy can be captured by both the vertical and side-to-side motion of the structure. The Pelamis system is slack moored perpendicular to the wave crest and is capable of extracting energy multiple times as the wave passes its three hinge points. The commercial scaled system is 180m in overall length with a diameter of 4m. It has four modules with three electrical generators capable of producing up to 750 kW.[23] Wave parks are constructed by anchoring multiple Pelamis systems at the same location. The Pelamis system is not capable of storing energy onboard. All energy produced is fed into a grid via benthic energy transfer cables. In terms of ship integration for Sea Base operations, one or more Pelamis systems could be scaled to a manageable size and carried by a ship. If scaled properly, Pelamis systems could be held in well decks or in recessed compartments between hulls on catamarans, trimarans, and quadramarans.

Figure 5. Pelamis wave energy converter [23]

Wave Dragon

The Wave Dragon converts wave energy to electrical energy by channeling waves toward an elevated platform equipped with vertical turbines in the deck. Wave reflectors extend from the platform to channel 300m of wave breadth toward a 140m wide ramp leading up to the platform. The waves wash up the ramp and onto an elevated platform. The water rushes through vertically oriented turbines in the floor of the platform. The turbine orientation is similar to that found in low head hydroelectric dams. Figure 6 shows a schematic of the Wave Dragon system. The turbines are the only moving parts of the entire system. The elevated platform is based on a barge concept and towed to location. The barge is capable of adjusting its freeboard through ballasting to maximize energy conversion in different sea states. Higher sea states allow a higher freeboard, and therefore, more potential energy for electrical conversion. The size of the barge can be increased to accommodate more turbines for a region with very high wave energy potential. The smallest design currently uses a barge 58m by 33m with 7 low-head Kaplan turbines in a 0.4 kW/m region for a rated power output of 20 kW. The largest design was made for a 48 kW/m region and uses a 390 by 220 meter barge and 16 to 24 turbines for a rated power output of 11 MW.[33] Like the Pelamis system, the Wave Dragon does not store the energy it captures. It is designed to feed into a grid using cables. Once on location, the Wave Dragon is moored using a slack-moored gravity anchor system to reduce forces on the mooring system and collector arms. The Wave Dragon could be integrated into a ship that has ballasting capabilities and a floodable deck. Otherwise, it could be towed behind the Sea Base and quickly assembled once the mooring is secured.

Figure 6. Wave Dragon energy converter [33]

Oscillating Water Column Technology

There are many scavenger designs that use oscillating water levels within a space to drive air flow through turbine rotary. If the space is open to the water at one end and to the air at the other, water will be forced in and out of the column by the passing waves. As the air at the top of the space passes through a nozzle it spins a system of turbine rotors. Symmetrical air foils allow the turbines to rotate in the same direction despite the direction of air flow. The nozzle provides a "simple means of transferring the low velocities and high forces of air compressed by sea waves into the high speeds and low forces required by conventional electrical generators".[5] Air turbines also provide a cost effective approach to gearing. Oscillating water column technology could easily be adapted for through-hull fittings in a ship to provide a means of capturing energy directly without having to deploy or tow large systems.

Anaconda Wave Energy Generator

The Anaconda wave energy generator uses a "bulge wave" formed in a long rubber hose by passing waves to drive a hydraulic turbine and electric generator. It is currently being developed by the British company Checkmate Seaenergy. The system uses a large diameter long rubber hose filled with water at low pressure to interact with the wave. It is aligned parallel to the wave direction and floats neutrally just below the water surface, as seen in Figure 7. It is moored at the bow in a manner similar to the Pelamis system. As the wave picks up the front of the hose, a bulge wave forms inside and travels in front of the wave until it hits a hydraulic turbine. It is predicted that the full size, 200m, "snake" will produce up to 1 MW of electricity.[2] The Anaconda has few moving parts and is fairly tolerant of ocean forces. The rubber hose makes it less bulky than the other systems already discussed. The full sized, collapsible rubber hose could be rolled up and carried by relatively small ships.

Figure 7. Anaconda wave energy generator [2]

Future Technology

Currently, the prototypes in operation are site specific and are deployed in particular wave climates for proof of concept testing. The companies have not published anything beyond the prototype's general dimensions, construction details, and calculated maximum output. Wave parameters related to advertized performance are not available. Therefore, it is unclear how wave data from other parts of the world could be used to calculate a theoretical output. It is also unclear how the different companies plan on scaling and fine tuning their prototypes.

Wind

Wind energy is a leader in clean renewable energy, producing up to 74GW worldwide in 2007.[29] Currently, only 600 MW of worldwide wind power is created offshore, with most being moored in shallow waters (<700m) on the continental shelf.[21] Development of offshore wind turbines moored in deeper water or deployment from ships without ocean floor mooring will be a challenge. Offshore wind is stronger and steadier, however, the effects of ship-induced motions on turbine performance and deployment issues are significant challenges not yet faced by offshore wind projects.

Wind energy scavengers vary in type and size. By taking the average of four manufactured turbine systems, a conservative efficiency of 35% was calculated.[17] Wind turbine performance is limited by the Betz law. This states that if the capture energy efficiency was a maximum 100%, the wind would completely stop and no longer flow past the turbine, impeding any wind energy conversion. A compromise between stopping the air and letting it flow past the turbine must be made for all types of wind conversion systems.

Present Technology

Horizontal Axis Wind Turbines

The wind turbine industry is currently focused on horizontal axis wind turbines (HAWT) as they are the most mature technology and have been used throughout the past few decades. Table 1 summarizes the size and power of various horizontal axis wind turbines.

In this developed industry, virtually any size turbine with rotors up to 40m in diameter can be bought "off the shelf".[11]

Rotor Diameter (m)	Swept Area (m^2)	Rated Power Capacity Range (kW)	Specific Rated Capacity (kW/m2)
12.5	125	40-60	0.3-0.5
18	250	80-100	0.3-0.4
25	500	200-300	0.4-0.6
35	1000	300-400	0.3-0.4
40	1250	500-750	0.4-0.6

Table 1. Typical medium sized HAWT diameters and power capacities [11]

Many offshore wind turbines are tethered to the sea floor, which poses problems for the utilization and deployment of wind turbines on an energy scavenging ship. The two types of mooring systems used are Tension Leg Platform (TLP) mooring and Catenary mooring systems.[29] TLP mooring uses vertical tethers under tension to provide large restoring moments in pitch and roll. Catenary mooring systems provide station-keeping for an offshore structure with little stiffness at low tensions.

The array efficiency of a group arrangement of turbines is defined as the ratio of total wind energy yield of the array to the sum of total energy yields of all individual turbine units without neighboring obstructions. It is greatly affected by wind turbine spacing. To avoid obstruction of air flow in a concentrated wind turbine area, appropriate turbine spacing depends on specific wind turbine characteristics, number of wind turbines, and wind turbulence intensity.[14] Although wind direction does not affect the expected power output by a single wind turbine, the shadowing effect of air flow obstruction from different angles will affect energy output of a wind farm. Thus, annual distribution of the wind direction is typically used to predict energy outputs of a total area.

Future Technology

Vertical Axis Wind Turbines

There are a variety of turbines that are either newly tested or under development. The Vertical Axis Wind Turbine (VAWT) has a major advantage over HAWTs because they can cover a greater area of wind to create more electrical power with the same rotor diameter. Also, VAWTs are omni-directional, meaning that wind can blow in any direction without adverse effects. Maintenance is easier because VAWTs are mounted with bearings near the ground, allowing for better access to moving parts. However, when dealing with smaller winds, rotor heights are typically lower, meaning that VAWTs will take up more space than HAWTs.

Various types of VAWTs are produced by manufacturers such as Savonius turbines, Darrieus Turbines, Jellyfish Appliances, Superturbine, California SuperTwin, and Helix Turbine. Savonius Turbines have been developed to scoop incoming wind into its bulky rotors to produce 2.5-5kW with 3.6m/s cut-in speed using rotors 1.21m high at a height of 4.87m.[26] Jellyfish wind turbines are currently small-scaled, producing less than enough electricity to power an average house.[16] The SuperTurbine and California SuperTwin, are concepts developed by the company Selsam.[15] Data for these concepts was insufficient for analysis.

Flying Electric Generators

Winds at high altitudes are stronger and more consistent than wind at ground level. For this reason, the Flying Electric Generator (FEG) concept has been developed to harvest kinetic wind energy. The FEG prototype, while in flight, is connected to an electrical tether that is insulated by aluminum conductors designed to transmit 240 kW.[27] Smaller FEGs can hover as low as 4,600m. According to data from NOAA at these heights, the US average capacity factor for FEGs is about 80% which proves to be much higher than the 35% capacity factors of ground-based turbines.[28] An FEG prototype has been built to successfully produce 240 kW at 15,000 ft (4,600m).[28] Figure 8 below shows the prototype and an artist rendering of the full size turbine.

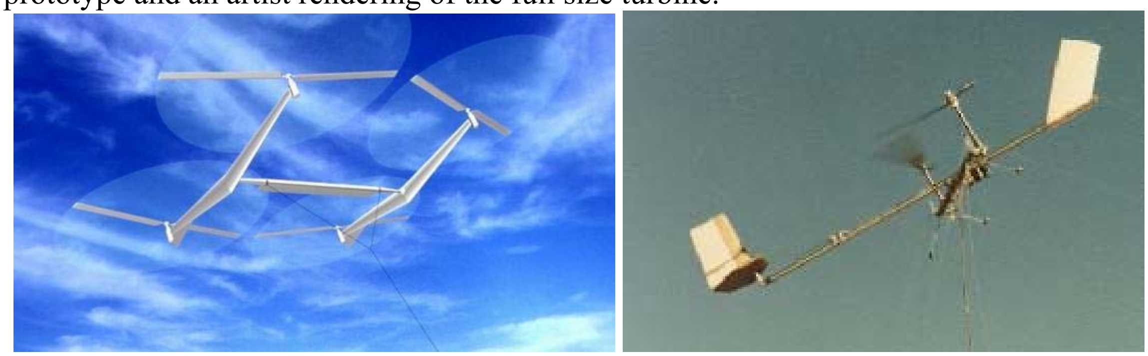

Figure 8. Artist rendering (left) and prototype (right) of the Flying Electric Generator [1,13]

FEGs are started up by power provided by the land base to lift the FEG using the spinning turbines in a helicopter form.[19] Once the FEG reaches a certain altitude and wind speed, it becomes energy independent using some of the electricity from its turbines to keep it in the air and giving its extra energy to the ground receiver. The autorotation speed tends to hover around 10 m/s minimum for 1,500 ft (4,600m) or 11.5 m/s at 15,000 ft (4,600m).[27] Commercial FEGs are predicted to have power densities that reach levels of 20 kW/m^2 at a latitude of 30°, which can produce from 3 to 30 MW. FEGs are kept in control using GPS.

FEGs seem to be somewhat suitable for ship based deployment given that a hanger-like structures and large clear landing platforms are available on certain mission platforms. They provide a large amount of power without having to take wave motion into design consideration. Some disadvantages for ship integration include landing and deployment around storms and lightning, large size, problems with tether maintenance and reliability, and the necessity for start up power to the FEG when being lifted up into the troposphere.

Magnetic Levitated Turbines

Magnetically Levitated Turbines (MagLev) have been demonstrated to be a viable future option for mass energy production. Using certain models that hold permanent magnets, no electricity is required to levitate the vertically oriented blades. These blades rotate linear generators with minimal friction losses producing up to 1 GW of energy. Cut-in speeds vary from 1.5-3 m/s while Mag Lev operation has the ability to continue at 40 m/s. The Chinese company, Zhongke Hengyuan Energy Technology, has produced a successful prototype generating 400 watts.[7] The major drawbacks for ship integration with large permanent magnets are the effects on other electrical systems and the requirement for platform stability for proper function.[10] Figure 9 depicts a scaled rendering of the MagLev system.

Figure 9. Large-scale MagLev [7]

3.0 Energy Collection

Ocean Measurements

To characterize the ocean's energy potential, seven locations around the world within the tropic and temperate regions were researched. The selected locations are listed below in Table 2 and Figure 10. These locations were chosen on the basis of current political events and humanitarian peacetime allies. Also, because reliable raw ocean data was difficult to find, these locations were points where data was readily available and consistently representative of neighboring areas around them.

Region	Latitude	Longitude
Latin America	17N	82W
Brazil	8S	30W
West Africa	12N	23W
Indian Ocean	8N	64E
Korea	38N	122E
Japan	28N	132E
Philippines	8N	137E

Table 2. Latitude and longitude of locations chosen for ocean data.

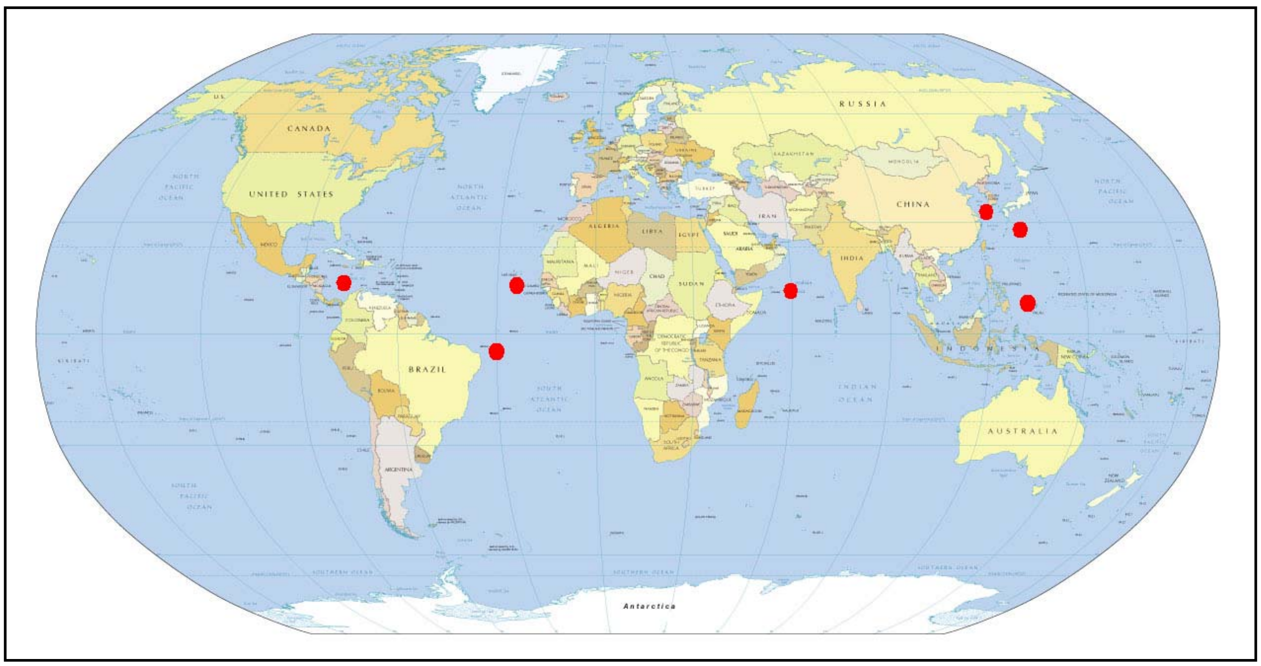

Figure 10. Map of the 7 locations chosen for ocean data collection.

Ocean data was collected from the National Data Buoy Center (NDBC) provided by the National Oceanic Atmospheric Administration (NOAA) and the Technical Memorandum "Coastal Marine Engineering: Environment Factors along Thirteen International

Coastlines". Daily data was collected over a span of 2-3 years. The types of data collected include:

- current speed (cm/sec)
- wind speed (m/sec)
- solar radiation (W/m^2)
- wave height (m)
- temperatures at ocean depths (°C)

This data was later used to estimate the energy potential for different energy sources.

Chart Progression

Data sets for each location were analyzed separately to find annual trends within each data set, the average, minimum, maximum, and the 75% confidence interval were calculated for each month and graphed over the span of one year for each data set. The 75% confidence interval was calculated to minimize outlier influence.

The following figures (Figure 10-14) show how data was presented for one location. The tables that accompany these figures and the tables for the other 6 locations are located in Appendix A.

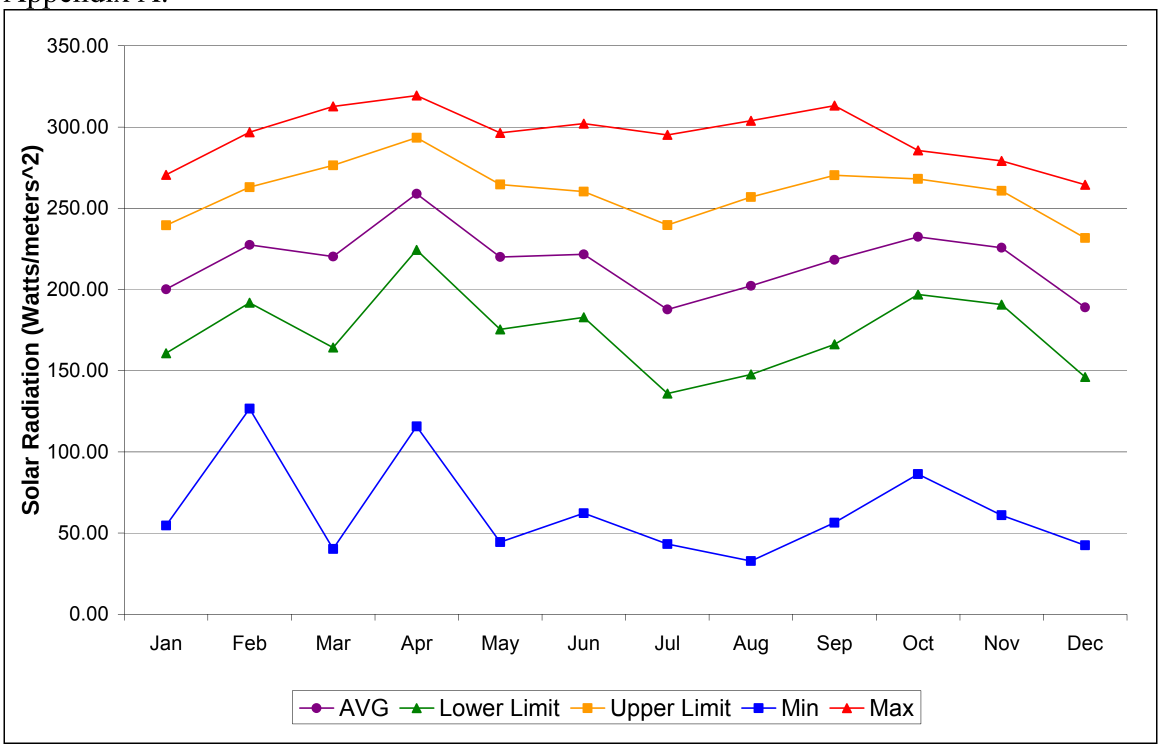

Figure 11. Monthly solar radiation (W/m^2) average, minimum, maximum, 75% confidence interval in Philippines over the course of one year.

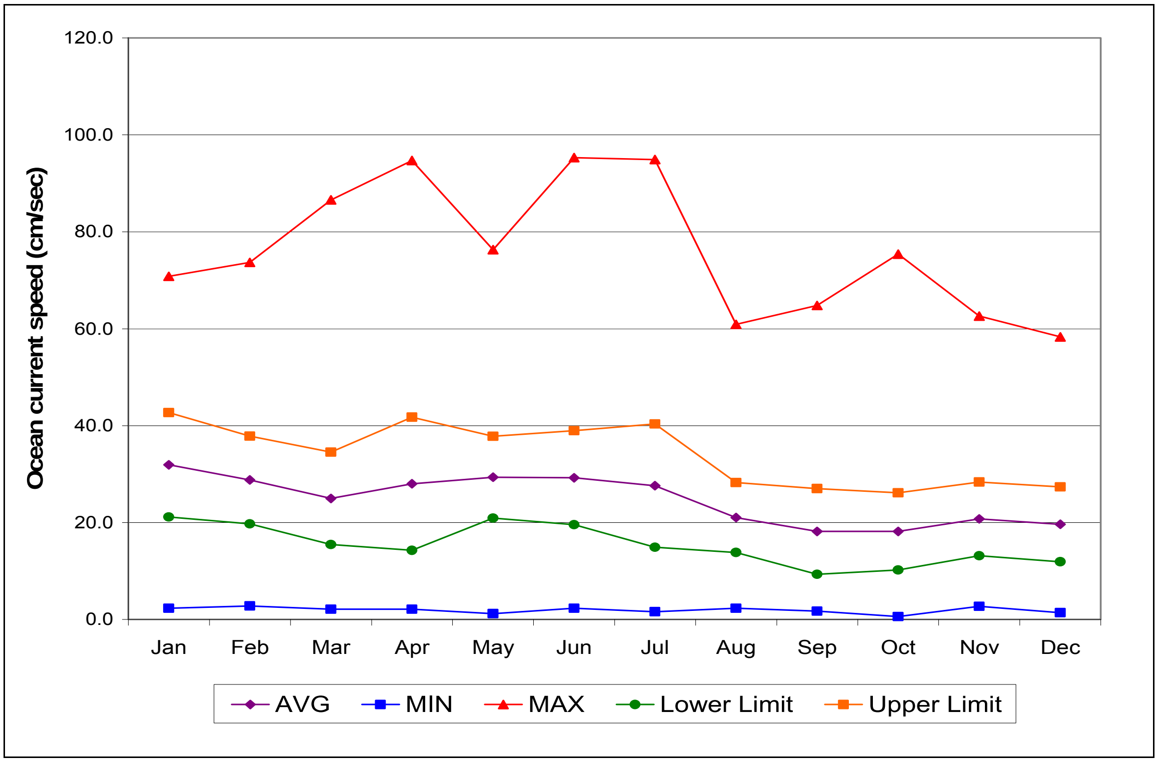

Figure 12. Monthly current speed (cm/sec) average, minimum, maximum, 75% confidence interval in Philippines over the course of one year.

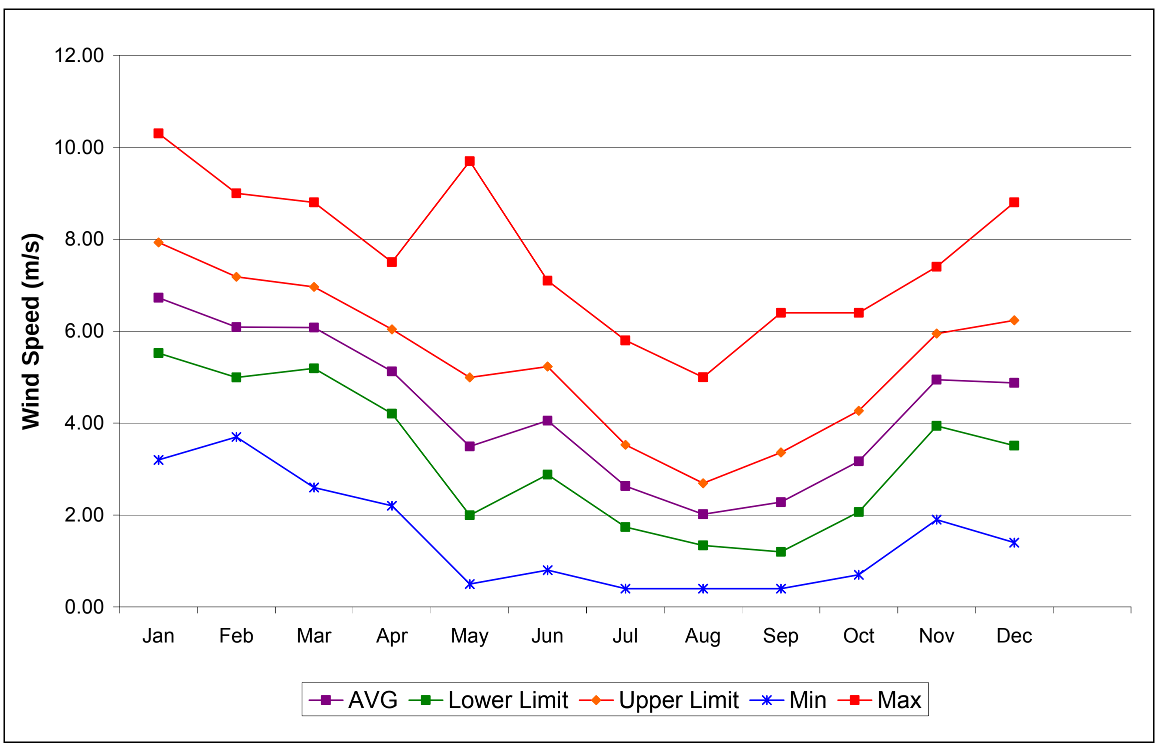

Figure 13. Monthly wind speed (m/sec) average, minimum, maximum, 75% confidence interval in Philippines over the course of one year.

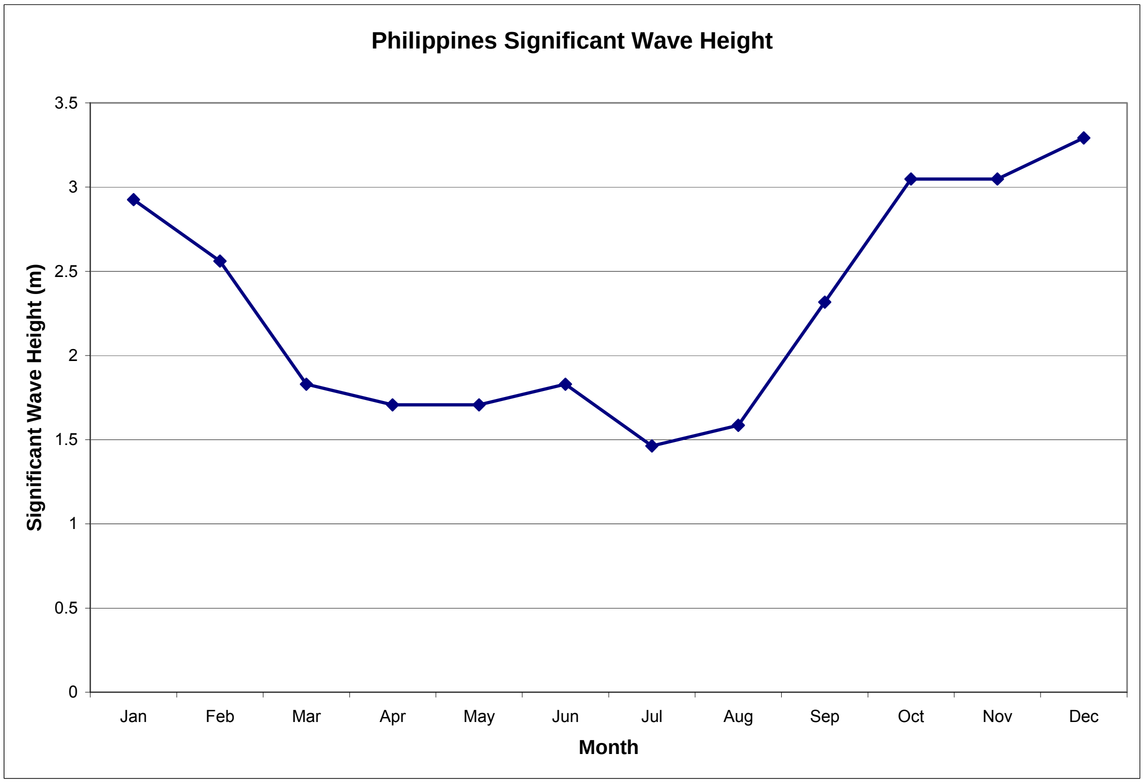

Figure 14. Significant wave heights in the Philippines.

Wave height data was collected from the Technical Memorandum "Coastal Marine Engineering: Environmental Factors Along Thirteen International Coastlines". It was presented in the form of monthly averages, therefore, the minimums, maximums, and 75% confidence intervals could not be calculated.

Energy Conversions

Raw data for each type were converted to watts to compare the energy potential with a unit area of $1m^2$ or a unit breath of 1m. This allows for a consistent comparison of energy potential for each type of power. The lower 75% confidence boundary of the raw data was used to yield conservative power outputs. The following relationships were used in this process.

<u>Solar</u>
Solar radiation values were given in W/m^2. To find the raw power from solar radiation, the values given are multiplied by an area.

$$P_{sol} = SolarRadiation \cdot Area \quad \textbf{(1)}$$

Wind

Wind speed values were converted to power by using the potential energy equation.

$$P_{wind} = \frac{1}{2}\dot{m}{v_W}^2 = \frac{1}{2}(\rho_{air} v_W A){v_W}^2 \quad \textbf{(2)}$$

Ocean Current

Current speed values are converted to power using the same potential energy equation.

$$P_{cur} = \frac{1}{2}\dot{m}{v_C}^2 = \frac{1}{2}(\rho_{water} v_C A){v_C}^2 \quad \textbf{(3)}$$

Wave

Wave power is generated as the flux of energy per unit crest length.

$$P_{wave} = \frac{\rho_{water} g^2}{64\pi}{H_s}^2 T_e \quad \textbf{(4)}$$

where, $\dot{m}$ = mass flow rate (kg/sec)
- ρ_{air} = density of air (kg/m^3)
- v_w = wind speed (m/sec)
- A = area (m^2)
- ρ_{water} = density of water (kg/m^3)
- v_C = current speed (m/sec)
- g = gravitational acceleration (m/sec^2)
- H_S = significant wave height (m)
- T_e = wave period (sec)

Wave period was estimated using the Pierson Moskowitz relationship between wave height and wave period.

Figure 15 summarizes the raw power levels that are available at one location. The other locations' raw power potential curves can be found in Appendix B. Note that the y-axis is on a logarithmic scale as wave power calculations yielded values that were 100 times the other calculated values.

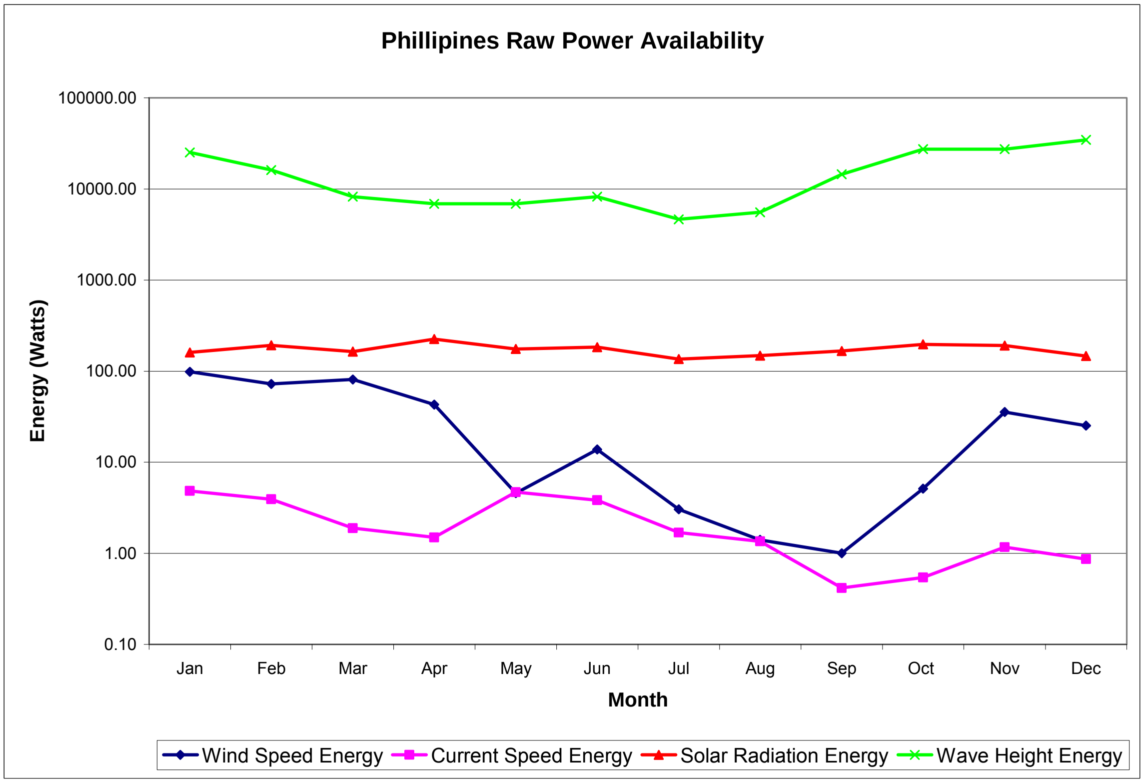

Figure 15. Raw power available in the Philippines.

Efficiency Conversions

The efficiencies of each harvesting method were researched and combined with the raw data to assess the potential of each energy collection technology. The efficiency for each type of energy is shown in Table 3. Efficiency values.. The efficiencies take into account all the energy losses from raw energy input to final machine and technology outputs.

Energy	Efficiency (%)
Solar	20
Bio	3
Wind	35
Current	37
Wave	40
OTEC	2.7

Table 3. Efficiency values.

The raw power levels were multiplied by the efficiencies and converted to the common units of W-hr/day. Results shown in Figure 16 are displayed in a logarithmic scale due to the large range of energy output levels.

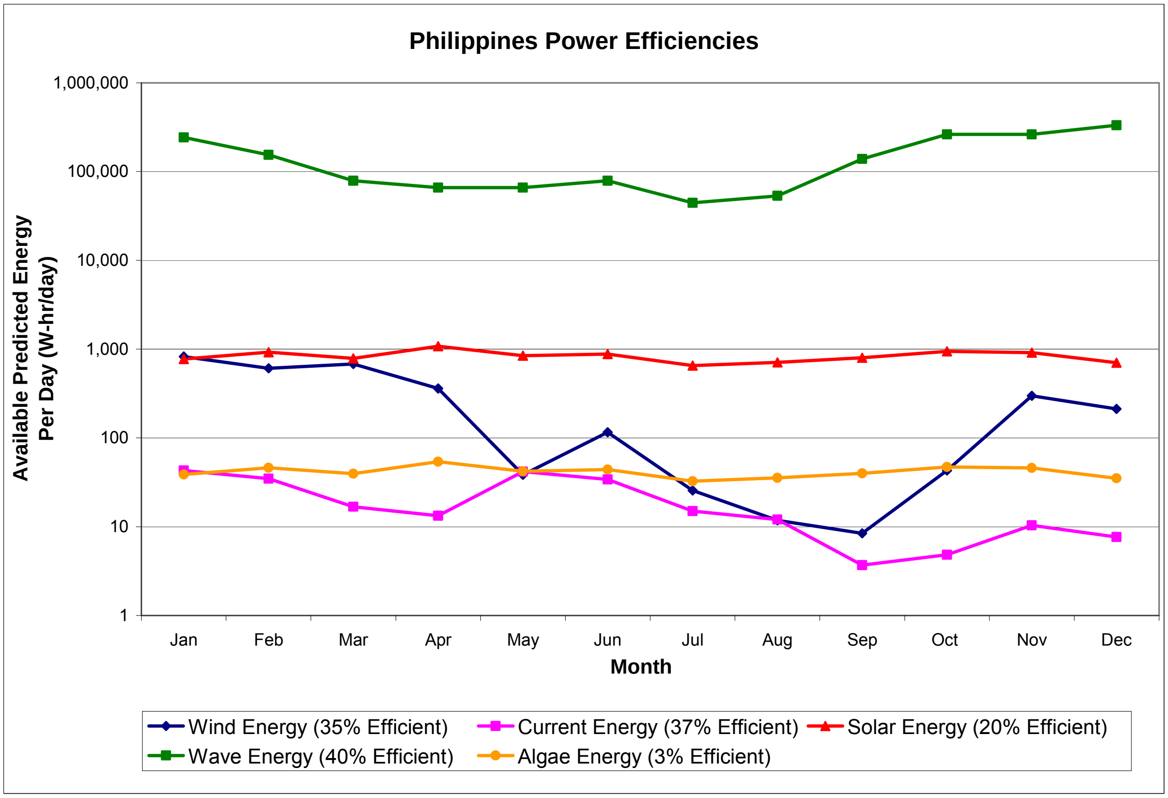

Figure 16. Potential power in the Philippines.

Figure 16 shows that wave energy produces the most power. Both wave and solar energy are fairly consistent throughout the year, however, solar energy is 1/1000 that of wave energy. Algae energy is calculated from solar radiation power levels because algae act as a biological solar panel. Ocean current energy produced the least amount of power, while wind and algae energy produced average amounts of power. The trends for the Philippine location are similar to the trends of all other 7 locations. Graphs for the other locations can be found in Appendix C.

OTEC systems were not included in this figure because they are not convertible down to a unit area. The OTEC system requires a total ship system for energy conversion, therefore, a separate graph was made to display the energy output levels from depth temperature differences. OTEC calculations, tables, and graphs can be found in Appendix D.

4.0 Evaluation and Assessment

After researching the different methods of harvesting energy, the most promising and reliable sources were selected for ship integration. This decision was reached through analysis of different criteria for ship integration and the effectiveness of each scavenging method. By narrowing down scavenging methods, more research and analysis could be done on ship integration for a future Sea Base Energy Scavenger design.

Criteria

To assess the reliability and suitability of different energy collection methods for ship integration, each system was evaluated according to the following weighted criteria:

- Deliverable energy (35%): The available raw energy from the ocean and efficiency of the harvesting method.
- Operations and maintenance (26%): The overall logistics of maintaining harvesting systems from a ship platform.
- Maturity and Interest (13%): What technology exists that is currently being used to collect energy and what future advancements are being done to increase the efficiency of the technology.
- Initial cost (6%): Capital cost of technologies used to harvest energy.
- Environmental impact (20%): How the technology and byproducts will affect the surrounding environments.

Each criterion was given a weight out of 100 based on its importance and prevalence to offshore energy scavenging for ship integration specified by the project requirements.

Scoring Scale

To score each type of energy for each criterion, a Likert scale of 0 to 10 in Table 4 was utilized. Each number was assigned a definition for consistency. Scores were given based on the efficiency data and the research previously conducted.

Scale	Definition
0	Not possible for ship design
1	-
2	Horrible
3	-
4	Fair
5	Satisfactory
6	Good
7	-
8	Very good
9	-
10	Excellent

Table 4. Likert scoring scale.

Analysis of Energy Types

Table 5 summarizes the scores that were given to each type of harvesting method for each criterion. The totals were calculated by taking the score out of 10 and multiplying it by the weight of the category. Then by summing the criterion scores, the total score was calculated.

Criteria	Weight	Solar	Bio Hydrogen	Wind	Current	Wave	OTEC	Biodiesel
Deliverable energy	35	7	3	6	2	8	8	3
Operation and maintenance	26	8	3	5	2	6	6	3
Research and development	13	9	7	8	4	7	4	7
Initial cost	6	6	4	7	3	3	1	4
Environmental impact	20	8	8	8	5	8	7	8
Total	**100**	**76.6**	**45.8**	**64.6**	**29.2**	**70.5**	**63.4**	**45.8**

Table 5. Evaluation and assessment matrix.

Reasoning

The table shows that solar energy, wind energy and wave energy scored the highest and have the greatest potential for an energy scavenging ship.

Solar scored particularly high because of the abundant amounts of raw solar energy available. Solar radiation throughout the world is generally constant and can yield high power levels. Also, the technology used to harvest solar energy is constantly improving. Although solar panels and the materials used are expensive, there is minimal environmental impact because there are no mechanical moving parts requiring lubricants that could leak or cause damage or harm to wildlife. This also makes solar technologies relatively easy to maintain and operate.

Wave energy yielded the highest amounts of energy output. It was at least 100 times the solar radiation power levels. Wave energy harvesting is a promising method because existing research has shown potential to harvest large outputs of energy. Wave energy prototypes and tests have shown that the mooring and rigging of wave generators is fairly simple and does not require much maintenance. Also, to prevent harming the environment, biodegradable liquids are used in the machinery.

Wind energy is a reliable source of energy and has the 3rd highest raw energy input. Although the operations and maintenance of wind turbines are more extensive because of rigging, mooring and stability issues, the capital cost of turbines are relatively low.

5.0 Data Analysis

General Information

The purpose of this study is to develop a set of tools that estimate a ship's maximum energy collection potential. To accomplish this, a set of interactive Microsoft Excel spreadsheets were constructed using data and information gathered throughout the study. Each spreadsheet focuses on one of seven regions that the Navy operates in frequently. It estimates energy capture potential for 58 commonly used Navy and civilian ships of varying size and hull geometry. The ships all have a displacement under 10,000LT. Monohulls, catamarans, SWATH's, trimarans, and quadramarans are included. Length overall, maximum breadth, collection area, and displacement data are given in the spreadsheet. Each ship's collection area was calculated by multiplying the length overall (LOA) and the maximum breadth. Within each spreadsheet, the user inputs the region's monthly solar radiation and wind energy data in W-hrs/day per square meter. If the user wishes to integrate a horizontal or vertical axis turbine, they must also enter the turbine's rotor diameter. The spreadsheet then calculates the maximum amount of energy that can be collected by each ship in a single day for each month. Each of the three chosen energy collection systems was integrated into the ships to determine their maximum energy collection potential in the different regions. The spreadsheet computes the maximum, minimum, and average solar energy collection per month. It calculates HAWT and VAWT collection for a conservative and maximum collection arrangement per month. The differences between the two arrangements will be discussed later in the paper.

Solar Panel Production Data

Solar energy collection was calculated first. It was calculated assuming that solar panels cover the entire collection area of the ship. The region's solar radiation $\left(\frac{W-hrs/Day}{m^2}\right)$ was multiplied by the usable deck area of the ship (m^2) to determine its possible solar energy collection in watt-hours per day. The solar radiation data in the spreadsheets was collected from buoy data and multiplied by a solar panel efficiency of 20%. The spreadsheet multiplies the available energy by the collection area to determine the maximum solar collection potential for each ship. The equation is listed below as Equation 5.

$$P = (Solar\ Radiation \times System\ Efficiency) \times LOA \times Max\ Breadth \qquad \textbf{(5)}$$

Wind Turbine Production Data

With the spreadsheet, the user can calculate VAWT and HAWT energy production simultaneously. The energy output can be estimated with either conservative or maximum production assumptions. Calculating wind turbine production is more difficult than calculating solar production because wind turbines have strict spacing requirements. Both types of turbines reduce wind speed as they convert energy and create turbulence down wind and to either side. A turbine's disturbances can significantly reduce the output of the turbines surrounding it if the minimum spacing requirements are not met. Horizontal axis turbines create more disturbances than vertical axis turbines and therefore require more space. A HAWT requires a clearance of 10 times its rotor diameter fore and aft in the direction of the wind and a clearance of 5 times its rotor diameter perpendicular to the wind direction. A VAWT requires 8 times its rotor diameter in the direction of the wind and 3 times its rotor diameter perpendicular to the wind direction. According to the book "Wind Turbines Fundamentals, Technologies, Application, Economics by Erich Hau, these arrangements keep the array efficiencies at 90%.[14] It will, however, take stronger winds to spin all turbines together in these arrangements than it would if they were stand alone systems. By aligning the grid of turbines fore and aft on the ship, the required spacing is guaranteed even when the ship is not going into the wind. For more details on spacing of the two turbines types, see Figure 17.

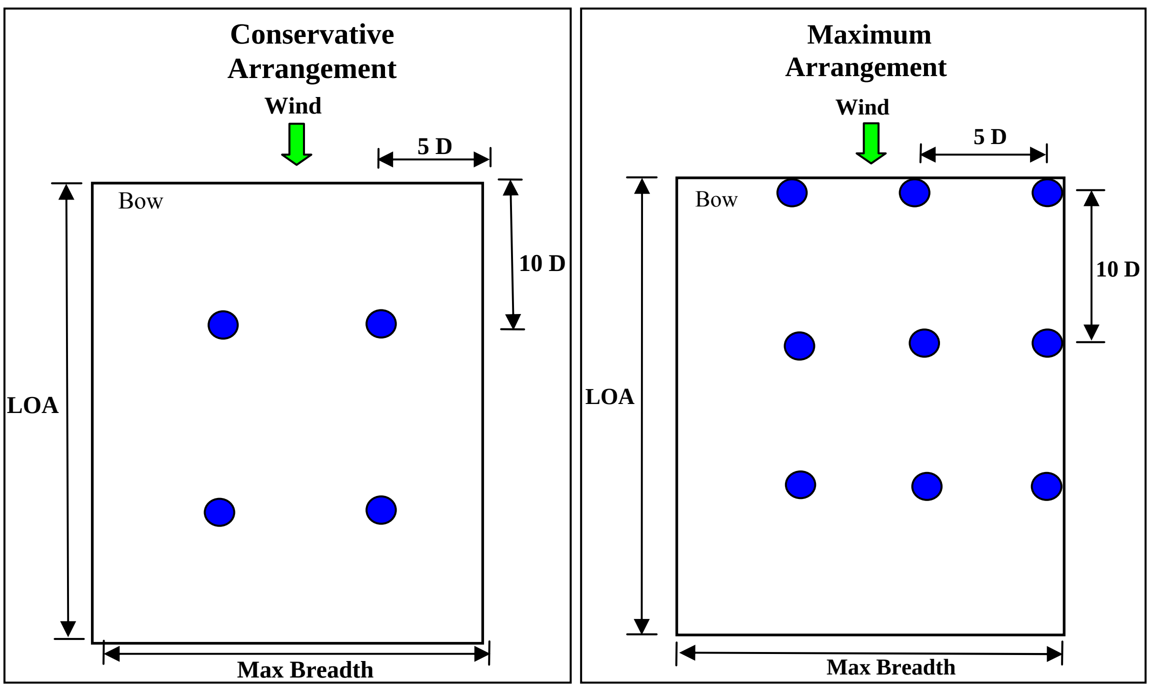

Figure 17. Conservative (left) and maximum (right) turbine spacing for HAWTs.

The strict turbine spacing required that the ship's usable deck area be broken up according to the rotor diameter into fixed grids. If a grid could not fit completely on the deck, it was not included. The amount of watt-hours produced by each turbine daily was calculated by multiplying the available wind energy and efficiency $\left(\frac{W-hrs/Day}{m^2}\right)$ by the capture area of each turbine (m^2). The number of turbines was multiplied by the energy output of each turbine and an efficiency of 35% to find the total energy output per ship. This algorithm is called the conservative arrangement because it keeps all clearances within the ship's footprint. The equations are used to calculate the conservative arrangement's potential collection is listed below as Equations 6 and 7.

Conservative Production Arrangement

HAWT

$$\left(\frac{LOA}{10\times D}\right)\times\left(\frac{B}{5\times D}\right)\times\frac{\pi\times D^2}{4}\times E\times\varepsilon \tag{6}$$

VAWT

$$\left(\frac{LOA}{8\times D}\right)\times\left(\frac{B}{3\times D}\right)\times H\times D\times E\times\varepsilon \tag{7}$$

where, LOA = Length Overall (m)
D = Rotor Diameter (m)
B = Maximum Breadth (m)
E = Available Wind Energy (W/m^2)
ε = Turbine Efficiency (%)
Note: Round all calculations in parenthesis down to the nearest whole number.

The maximum production arrangement allows turbines mounted to extend beyond the deck edge. By allowing half the clearance to extend over the water, extra turbines can be fitted both athwartships and longitudinally. The maximum arrangement equations are listed below as Equations 8 and 9. The maximum arrangement significantly increases a ship's energy collection potential.

Maximum Production Arrangement

HAWT

$$\left(\frac{LOA}{10\times D}+1\right)\times\left(\frac{B}{5\times D}+1\right)\times\frac{\pi\times D^2}{4}\times E\times\varepsilon \tag{8}$$

VAWT

$$\left(\frac{LOA}{8\times D}+1\right)\times\left(\frac{B}{3\times D}+1\right)\times H\times D\times E\times\varepsilon \tag{9}$$

Where, LOA = Length Overall (m)
D = Rotor Diameter (m)
B = Maximum Breadth (m)
E = Available Wind Energy (W/m^2)
ε = Turbine Efficiency (%)
Note: Round all calculations in parenthesis down to the nearest whole number.

Wave energy calculations were not incorporated into the spreadsheet because of the lack of output data for different system sizes and sea states. There was not enough published data to come up with a way to scale the different systems for the different ship characteristics and sea states. However, the Anaconda Wave Energy Generator seems most feasible for ship integration at this time. The flexible, inflatable rubber hose makes integration easier because the bulk of the system can be rolled up and stored on reels. The Anaconda was the only system investigated that could fit the ships in the study without scaling. The chart below shows the possible integration of the system and its outputs. From the chart, it can be concluded that multi-hulled ships will likely be able to carry and deploy more Anaconda systems and therefore collect more energy.

Ship Type	Number of Systems	Convertible Energy
Monohull	2	2 MW
Twin Hull	3	3 MW
Trimaran	4	4 MW
Quadramaran	5	5 MW

Table 6. Wave energy summary.

Summary

The spreadsheet provides a designer with the preliminary information needed to begin an energy scavenger ship design. Prior to its construction, it was unknown how much solar and wind energy could be captured on a ship scale. There is now a tool to validate decisions on hull type, region, and technology. This tool allows a designer to analyze the energy scavenging characteristics of different systems and platform sizes. Below are conclusions that have been reached using the spreadsheet.

From the spreadsheet, it was concluded that a solar panel system is capable of collecting on average 15 times the annual energy that a vertical axis wind turbine array can capture in the maximum arrangement. The spacing requirements of the wind turbines reduce the capture area significantly. Table 7 shows the annual collection potential of the two systems in the seven chosen regions. It uses a high speed semi-SWATH hull form with a length of 126.6m and a maximum breadth of 40m. The wind turbine data was calculated using a rotor diameter of 3 meters.

Region	Predicted Annual Solar Panel Output (MW-hrs/Year)	Predicted Annual Wind Turbine Output (MW-hrs/Year)
Japan	46	3
Philippines	51	2
West Africa	55	4
Indian Ocean	54	5
Korea	Data not found	0.6
Brazil	68	8
Latin America	Data not found	14

Table 7. Predicted annual energy output comparison.

From the spreadsheet, it was determined that multi-hulled ships are more suitable for an energy scavenging ship. This is because the multi-hulls have a much larger breadth for a given deck area ratio. They provide a capture area nearly twice as large as the monohulls of similar displacement.

The spreadsheet also shows that a vertical axis wind turbine arrays can collect 5 times more energy than a horizontal axis array because of the spacing requirements. Horizontal axis turbines are a proven technology on land and are preferred over vertical axis turbines. However, the large expanses of area on land are not available on a ship. Instead, the rectangular profile, small footprint, low disturbances, and weight distribution of the vertical axis turbines make them significantly better for ship integration.

This study has identified potential renewable energy sources and quantified temporal distribution of them at 7 locations around the world representative of Navy operations. Harvesting technologies and characteristics for each type of energy were identified and evaluated for ship integration. Solar, wave and wind have consistent available energy throughout the year and have most potential for energy collection on a Sea Base Energy Scavenger. Wave energy has 100 times more potential power than solar or wind energy. Because wave energy prototypes have not been used in commercial implementation, more data is needed to scale wave systems to ship designs. Lastly, it was observed that multihull ships are better for energy scavenging systems due to their geometric shape, stability, and weight distribution.

Future Recommendations and Research

The spreadsheet could be developed further to make it easier to use and more adaptable to different regions and technologies. A cell could be assigned "System Efficiency" and the user could input the current technology's efficiency into that space and designate whether it is a solar or wind energy scavenger. They would then enter the region's lower 75% confidence interval energy potential (W/m^2) by month. An equation could be added that calculates the region's possible energy collection for each ship. The spreadsheet could also be reworked to calculate interferences if multiple systems were to be integrated in the same collection area.

The completion of this project will give future researchers tools that will aid in the initial conceptual ship design of a Sea Base Energy Scavenger. In future application, designers can use the energy output results of different ship sizes for the application to powering conventional or unmanned systems. The energy levels will signify whether or not a method of energy scavenging with a ship certain ship will generate enough power to meet a mission's need.

Future research should focus on finding ways to store and transfer energy collected by the Sea Base. Suitable energy storage systems on ships do not currently exist, therefore, developing ways to store and transfer energy to ships is an innovative part of the Sea Base Energy Scavenger. Evaluating useful by-products of the energy collection systems, such as fresh water, should be assessed for their value and practicality. Research on energy scavenging methods should be constantly updated. New technologies with improved efficiencies and scavenging methods are continually being developed due to ongoing research in this field. Eventually, a Sea Base Energy Scavenging ship, with integrated energy systems will be designed based on the conclusions in this phase of the study to harvest, store and distribute energy in different areas around the world.

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7.0 Appendices

Appendix A. Raw Ocean Data Tables

A.1 Solar Radiation (W/m^2)

Brazil (2007-2008)

	AVG	MIN	MAX	STDEV	75% Confidence Interval	
					Lower Limit	Upper Limit
Jan	284	224	318	21	270	297
Feb	289	136	325	29	271	307
Mar	274	75	327	47	245	303
Apr	255	140	302	38	231	279
May	229	79	280	45	200	257
Jun	206	16	259	47	177	236
Jul	214	55	264	43	187	241
Aug	245	113	289	32	225	265
Sep	255	193	300	25	239	271
Oct	277	180	317	30	259	296
Nov	288	231	326	26	271	304
Dec	293	245	327	18	282	305

Indian Ocean (2007)

MONTH	AVG	MIN	MAX	STDEV	75% Confidence Interval	
					Lower Limit	Upper Limit
Jan	229	NO DATA	NO DATA	NO DATA	167	291
Feb	254	NO DATA	NO DATA	NO DATA	205	304
Mar	225	NO DATA	NO DATA	NO DATA	169	280
Apr	265	NO DATA	NO DATA	NO DATA	249	281
May	211	NO DATA	NO DATA	NO DATA	172	251
Jun	175	NO DATA	NO DATA	NO DATA	132	218
Jul	191	NO DATA	NO DATA	NO DATA	150	233
Aug	222	NO DATA	NO DATA	NO DATA	191	254
Sep	234	NO DATA	NO DATA	NO DATA	191	278
Oct	232	NO DATA	NO DATA	NO DATA	193	271
Nov	267	NO DATA	NO DATA	NO DATA	221	312
Dec	218	NO DATA	NO DATA	NO DATA	167	268

Japan (2004)

MONTH	AVG	MIN	MAX	STDEV	75% Confidence Interval	
					Lower Limit	Upper Limit
Jan	195	45	257	60	155	236
Feb	197	63	266	54	161	234
Mar	207	63	267	44	177	237
Apr	187	63	274	63	144	229
May	204	81	276	54	168	241
Jun	182	31	279	69	136	229
Jul	227	98	278	43	197	256
Aug	180	70	267	60	140	221
Sep	230	43	279	53	194	266
Oct	209	73	271	56	171	247
Nov	189	58	252	48	157	222
Dec	168	67	242	51	134	203

Korea
Data Not Available

Latin America
Data Not Available

Philippines (2006)

MONTH	AVG	MIN	MAX	STDEV	75% Confidence Interval	
					Lower Limit	Upper Limit
Jan	200	55	271	58	161	239
Feb	227	127	297	53	192	263
Mar	220	40	313	83	164	276
Apr	259	116	319	51	224	293
May	220	44	296	66	175	265
Jun	222	62	302	57	183	260
Jul	188	43	295	77	136	240
Aug	202	33	304	81	148	257
Sep	218	56	313	77	166	270
Oct	232	86	285	53	197	268
Nov	226	61	279	52	191	261
Dec	189	42	264	63	146	232

West Africa (2007-2009)

MONTH	AVG	MAX	MIN	STDEV	75% Confidence Interval Lower Limit	75% Confidence Interval Upper Limit
Jan	163	222	33	37	138	187
Feb	203	285	55	53	167	238
Mar	235	311	88	47	204	267
Apr	249	298	116	33	227	271
May	267	321	214	27	249	285
Jun	257	329	127	43	228	286
Jul	221	289	115	33	199	243
Aug	211	290	107	46	180	242
Sep	210	263	139	25	193	227
Oct	192	235	87	28	173	211
Nov	173	211	99	27	155	191
Dec	167	206	26	46	136	198

A.2 Wind Speed (m/s)

Brazil (2006-2008)

Month	AVG	MIN	MAX	STDV	Lower Limit 75% CI	Upper Limit 75% CI
Jan	6.6	4.1	8.6	0.9	6.0	7.2
Feb	5.7	1.6	8.2	1.0	5.1	6.4
Mar	5.7	2.5	8.3	1.2	4.9	6.5
Apr	5.6	1.6	8.7	1.3	4.7	6.5
May	6.2	2.5	9.4	1.5	5.2	7.2
Jun	7.7	4.4	10.0	1.2	6.9	8.5
Jul	7.4	4.9	10.4	1.2	6.6	8.3
Aug	7.6	3.5	9.9	1.2	6.8	8.4
Sep	8.0	5.6	10.2	0.9	7.4	8.6
Oct	7.5	4.1	9.4	0.8	7.0	8.1
Nov	7.1	5.9	8.6	0.7	6.6	7.5
Dec	6.6	5.1	8.2	0.8	6.1	7.1

Indian Ocean (2007-2009)

Month	AVG	MIN	MAX	STDV	Lower Limit 75% CI	Upper Limit 75% CI
Jan	4.0	0.8	9.3	NO DATA	2.0	6.0
Feb	4.3	1.1	8.3	NO DATA	3.1	5.5
Mar	4.7	0.9	8.3	NO DATA	3.2	6.2
Apr	3.3	1.1	6.5	NO DATA	2.3	4.4
May	6.3	3.0	9.6	NO DATA	4.9	7.7
Jun	7.7	4.7	11.2	NO DATA	6.6	8.8
Jul	7.8	6.0	10.7	NO DATA	7.1	8.9
Aug	8.5	6.8	9.7	NO DATA	7.9	9.0
Sep	8.2	3.5	10.2	NO DATA	7.3	9.2
Oct	6.7	1.6	9.6	NO DATA	5.2	8.1
Nov	4.2	0.9	7.4	NO DATA	3.1	5.4
Dec	5.4	0.8	10.5	NO DATA	4.0	6.9

Japan (2003, 2008)

Month	AVG	MIN	MAX	STDV	Lower Limit 75% CI	Upper Limit 75% CI
Jan	6.6	0.7	10.2	2.4	5.0	8.3
Feb	7.7	4.9	9.7	1.3	6.8	8.5
Mar	6.9	5.1	9.9	1.2	6.1	7.7
Apr	5.9	2.5	9.0	1.5	4.9	6.9
May	5.4	1.1	9.1	2.2	3.9	6.9
Jun	4.6	1.5	7.0	1.4	3.6	5.6
Jul	3.3	0.5	7.0	2.0	1.9	4.7
Aug	3.1	0.6	7.4	1.9	1.8	4.4
Sep	3.0	0.4	6.1	1.4	2.0	3.9
Oct	3.0	0.8	5.4	1.3	2.2	3.8
Nov	2.5	0.5	5.7	1.5	1.5	3.5
Dec	5.8	0.7	9.7	2.0	4.4	7.1

Korea (N/A)

Month	AVG	MIN	MAX	STDV	Lower Limit 75% CI	Upper Limit 75% CI
Jan	5.7	NO DATA	NO DATA	4.1	2.9	8.4
Feb	5.1	NO DATA	NO DATA	3.9	2.5	7.7
Mar	4.8	NO DATA	NO DATA	3.2	2.6	7.0
Apr	3.9	NO DATA	NO DATA	2.5	2.2	5.6
May	3.7	NO DATA	NO DATA	2.4	2.0	5.3
Jun	3.5	NO DATA	NO DATA	2.3	2.0	5.1
Jul	3.5	NO DATA	NO DATA	2.3	2.0	5.1
Aug	3.7	NO DATA	NO DATA	2.5	2.0	5.4
Sep	4.6	NO DATA	NO DATA	3.0	2.6	6.7
Oct	5.4	NO DATA	NO DATA	3.4	3.0	7.7
Nov	5.9	NO DATA	NO DATA	3.6	3.5	8.3
Dec	6.1	NO DATA	NO DATA	3.7	3.6	8.6

Latin America (2005-2008)

Month	AVG	MIN	MAX	STDV	Lower Limit 75% CI	Upper Limit 75% CI
Jan	5.4	NO DATA	NO DATA	NO DATA	4.6	6.1
Feb	4.9	NO DATA	NO DATA	NO DATA	4.2	5.6
Mar	4.5	NO DATA	NO DATA	NO DATA	3.8	5.2
Apr	5.0	NO DATA	NO DATA	NO DATA	4.8	5.2
May	5.6	NO DATA	NO DATA	NO DATA	4.2	7.0
Jun	6.1	NO DATA	NO DATA	NO DATA	4.8	7.5
Jul	6.7	NO DATA	NO DATA	NO DATA	5.4	8.0
Aug	5.7	NO DATA	NO DATA	NO DATA	4.6	6.9
Sep	5.3	NO DATA	NO DATA	NO DATA	4.2	6.5
Oct	4.5	NO DATA	NO DATA	NO DATA	2.9	6.0
Nov	5.3	NO DATA	NO DATA	NO DATA	4.1	6.5
Dec	6.0	NO DATA	NO DATA	NO DATA	4.9	7.2

Philippines (2008)

Month	AVG	MIN	MAX	STDV	Lower Limit 75% CI	Upper Limit 75% CI
Jan	6.7	3.2	10.3	1.8	5.5	7.9
Feb	6.1	3.7	9.0	1.6	5.0	7.2
Mar	6.1	2.6	8.8	1.3	5.2	7.0
Apr	5.1	2.2	7.5	1.4	4.2	6.0
May	3.5	0.5	9.7	2.2	2.0	5.0
Jun	4.1	0.8	7.1	1.7	2.9	5.2
Jul	2.6	0.4	5.8	1.3	1.7	3.5
Aug	2.0	0.4	5.0	1.0	1.3	2.7
Sep	2.3	0.4	6.4	1.6	1.2	3.4
Oct	3.2	0.7	6.4	1.6	2.1	4.3
Nov	4.9	1.9	7.4	1.5	3.9	5.9
Dec	4.9	1.4	8.8	2.0	3.5	6.2

West Africa (2007-2009)

Month	AVG	MIN	MAX	STDV	Lower Limit 75% CI	Upper Limit 75% CI
Jan	7.5	3.5	12.1	1.9	6.3	8.8
Feb	7.6	1.9	10.3	1.6	6.5	8.7
Mar	7.1	2.4	10.2	1.5	6.0	8.1
Apr	6.4	3.4	8.8	1.3	5.6	7.3
May	5.8	2.2	8.0	1.3	5.0	6.7
Jun	4.3	1.2	7.5	1.3	3.4	5.2
Jul	3.9	1.6	6.1	1.3	3.1	4.8
Aug	4.3	2.2	6.5	1.2	3.5	5.0
Sep	4.0	0.0	6.7	1.9	2.7	5.2
Oct	5.2	2.6	7.5	1.2	4.4	6.1
Nov	5.7	2.2	9.4	1.6	4.7	6.8
Dec	6.9	3.8	10.5	1.5	5.9	7.9

A.3 Ocean Current Speed (cm/sec)

Brazil (2006-2008)

Month	AVG	MIN	MAX	STDV	Lower Limit 75% CI	Upper Limit 75% CI
Jan	19.8	2.8	44.5	8.3	14.2	50.1
Feb	11.2	0.5	40.1	4.3	8.3	43.0
Mar	14.7	1.8	31.4	6.5	10.4	35.8
Apr	11.9	0.0	29.7	4.5	8.8	32.8
May	14.2	0.9	39.4	6.8	9.6	44.0
Jun	11.6	2.4	25.9	4.4	8.7	28.9
Jul	10.6	2.5	29.9	4.3	7.6	32.8
Aug	9.8	1.3	27.6	5.2	6.3	31.1
Sep	15.0	1.4	39.4	3.4	12.7	41.7
Oct	18.1	3.6	36.8	5.1	14.6	40.3
Nov	14.7	2.0	33.9	7.6	9.6	39.0
Dec	14.8	1.3	35.4	7.5	9.7	40.5

Indian Ocean (N/A)

Month	AVG	MIN	MAX	STDV	Lower Limit 75% CI	Upper Limit 75% CI
Jan	19.7	NO DATA	NO DATA	NO DATA	12.7	26.8
Feb	21.7	NO DATA	NO DATA	NO DATA	12.6	30.8
Mar	16.7	NO DATA	NO DATA	NO DATA	10.3	23.1
Apr	15.6	NO DATA	NO DATA	NO DATA	8.3	22.8
May	23.2	NO DATA	NO DATA	NO DATA	15.4	30.9
Jun	22.9	NO DATA	NO DATA	NO DATA	18.3	27.4
Jul	16.3	NO DATA	NO DATA	NO DATA	10.6	22.1
Aug	8.3	NO DATA	NO DATA	NO DATA	5.4	11.1
Sep	19.2	NO DATA	NO DATA	NO DATA	12.4	26.1
Oct	34.0	NO DATA	NO DATA	NO DATA	26.1	42.0
Nov	18.5	NO DATA	NO DATA	NO DATA	13.1	23.8
Dec	15.1	NO DATA	NO DATA	NO DATA	8.8	21.3

Japan (1999-2008)

Month	AVG	MIN	MAX	STDV	Lower Limit 75% CI	Upper Limit 75% CI
Jan	21.5	6.2	40.9	8.7	15.6	27.3
Feb	26.7	8.7	56.7	12.1	18.5	34.9
Mar	25.6	8.8	43.5	10.2	18.8	32.5
Apr	17.2	3.0	33.2	8.4	11.6	22.9
May	23.5	6.7	41.6	8.5	17.7	29.2
Jun	21.2	4.1	38.9	9.8	14.6	27.8
Jul	17.0	2.8	39.5	9.8	10.4	23.7
Aug	15.9	2.6	31.6	7.9	10.6	21.3
Sep	14.1	2.9	30.8	6.9	9.4	18.7
Oct	17.3	4.4	37.5	8.0	11.9	22.7
Nov	20.3	3.8	45.3	9.0	14.2	26.3
Dec	23.3	3.7	41.2	9.7	16.8	29.9

Korea (N/A)

Month	AVG	MIN	MAX	STDV	Lower Limit 75% CI	Upper Limit 75% CI
Jan	18.9	NO DATA	NO DATA	NO DATA	NO DATA	NO DATA
Feb	14.6	NO DATA	NO DATA	NO DATA	NO DATA	NO DATA
Mar	14.6	NO DATA	NO DATA	NO DATA	NO DATA	NO DATA
Apr	19.7	NO DATA	NO DATA	NO DATA	NO DATA	NO DATA
May	17.6	NO DATA	NO DATA	NO DATA	NO DATA	NO DATA
Jun	15.4	NO DATA	NO DATA	NO DATA	NO DATA	NO DATA
Jul	14.6	NO DATA	NO DATA	NO DATA	NO DATA	NO DATA
Aug	15.9	NO DATA	NO DATA	NO DATA	NO DATA	NO DATA
Sep	20.2	NO DATA	NO DATA	NO DATA	NO DATA	NO DATA
Oct	17.2	NO DATA	NO DATA	NO DATA	NO DATA	NO DATA
Nov	17.6	NO DATA	NO DATA	NO DATA	NO DATA	NO DATA
Dec	17.6	NO DATA	NO DATA	NO DATA	NO DATA	NO DATA

Latin America (2005-2008)
DATA NOT FOUND

Philippines (2002-2008)

Month	AVG	MIN	MAX	STDV	Lower Limit 75% CI	Upper Limit 75% CI
Jan	31.9	2.3	70.8	16.0	21.1	42.7
Feb	28.8	2.8	73.7	13.4	19.7	37.8
Mar	25.0	2.1	86.6	14.2	15.4	34.5
Apr	28.0	2.1	94.7	20.3	14.3	41.7
May	29.4	1.2	76.3	12.5	20.9	37.8
Jun	29.3	2.3	95.3	14.4	19.6	38.9
Jul	27.6	1.6	94.9	18.9	14.9	40.4
Aug	21.0	2.3	60.9	10.7	13.8	28.2
Sep	18.2	1.7	64.8	13.1	9.3	27.0
Oct	18.2	0.6	75.4	11.8	10.2	26.1
Nov	20.8	2.7	62.6	11.3	13.2	28.4
Dec	19.6	1.4	58.3	11.4	11.9	27.3

West Africa (2005-2009)

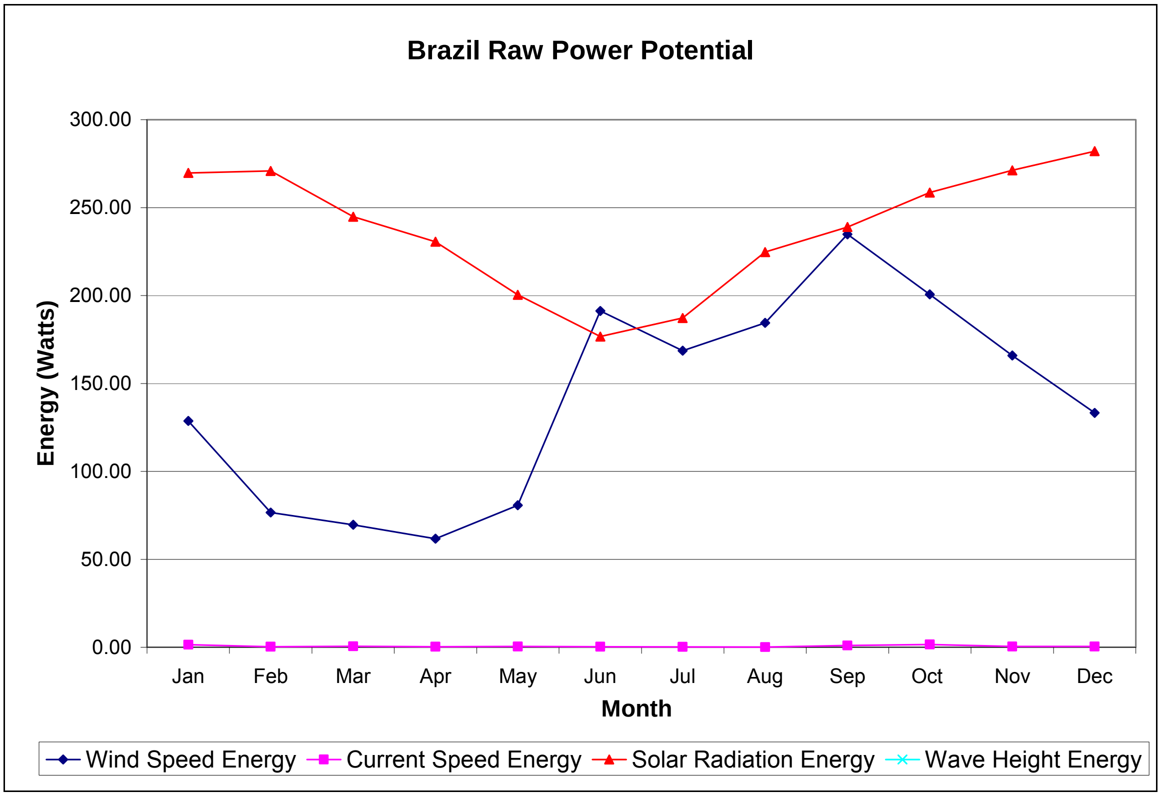
Month	AVG	MIN	MAX	STDV	Lower Limit 75% CI	Upper Limit 75% CI
Jan	37.7	3.1	78.0	18.0	25.5	49.8
Feb	24.8	0.0	46.7	11.9	16.7	32.8
Mar	16.9	1.1	49.4	10.4	9.9	24.0
Apr	21.1	1.4	46.4	11.2	13.5	28.7
May	27.7	0.0	76.9	14.3	18.0	37.4
Jun	37.7	3.0	99.2	24.7	21.0	54.4
Jul	41.1	1.5	89.9	21.5	26.6	55.6
Aug	38.3	2.7	85.3	22.6	23.0	53.5
Sep	22.8	0.8	67.4	14.6	12.9	32.6
Oct	29.4	1.6	64.6	14.0	20.0	38.9
Nov	25.9	1.1	61.6	14.0	16.4	35.3
Dec	35.3	2.2	98.8	20.3	21.6	49.0

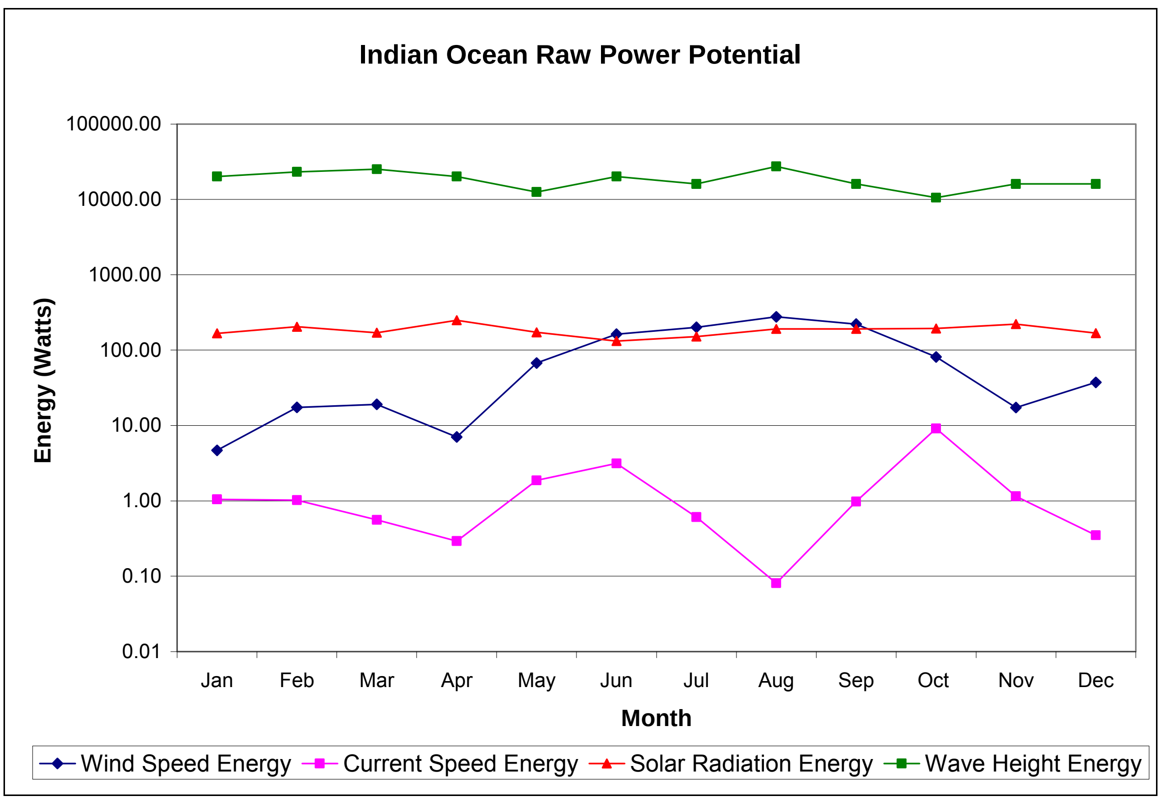
A.4 Wave Height (m)

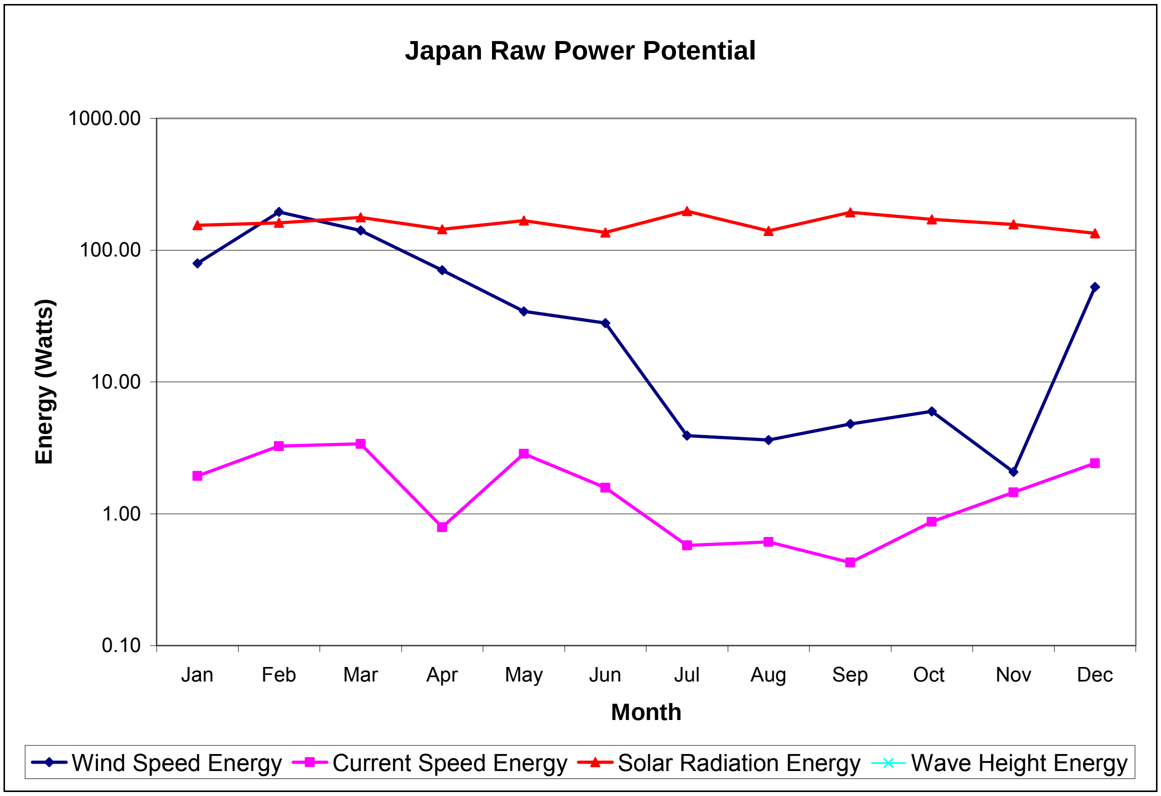
Significant Waveheight

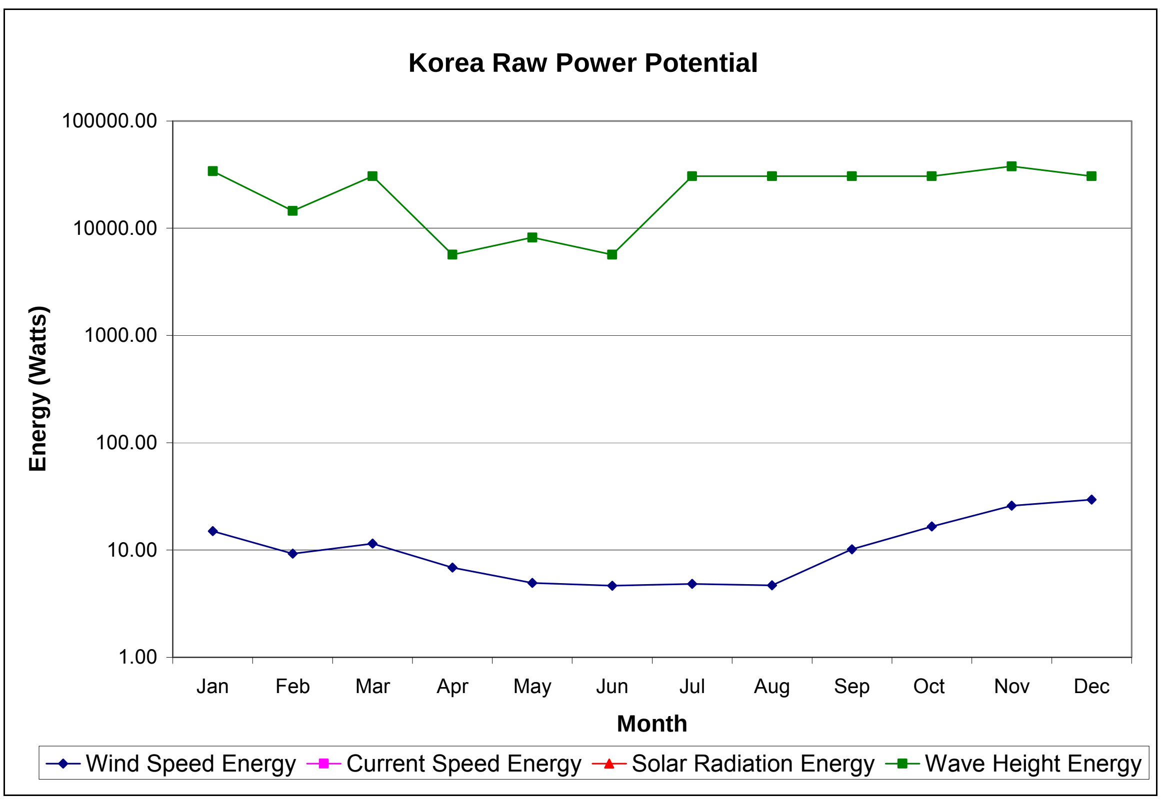
Month	Philippines	Japan	Korea	West Africa	East Brazil	Indian Ocean	Latin America
1	2.9	NO DATA	3.3	3.0	NO DATA	2.7	2.5
2	2.6	NO DATA	2.3	3.2	NO DATA	2.8	2.0
3	1.8	NO DATA	3.2	3.2	NO DATA	2.9	1.9
4	1.7	NO DATA	1.6	3.2	NO DATA	2.7	3.2
5	1.7	NO DATA	1.8	3.2	NO DATA	2.2	1.7
6	1.8	NO DATA	1.6	3.0	NO DATA	2.7	1.9
7	1.5	NO DATA	3.2	3.0	NO DATA	2.4	2.2
8	1.6	NO DATA	3.2	3.0	NO DATA	3.0	1.4
9	2.3	NO DATA	3.2	3.2	NO DATA	2.4	1.3
10	3.0	NO DATA	3.2	3.0	NO DATA	2.1	1.3
11	3.0	NO DATA	3.4	3.0	NO DATA	2.4	1.4
12	3.3	NO DATA	3.2	3.2	NO DATA	2.4	2.2

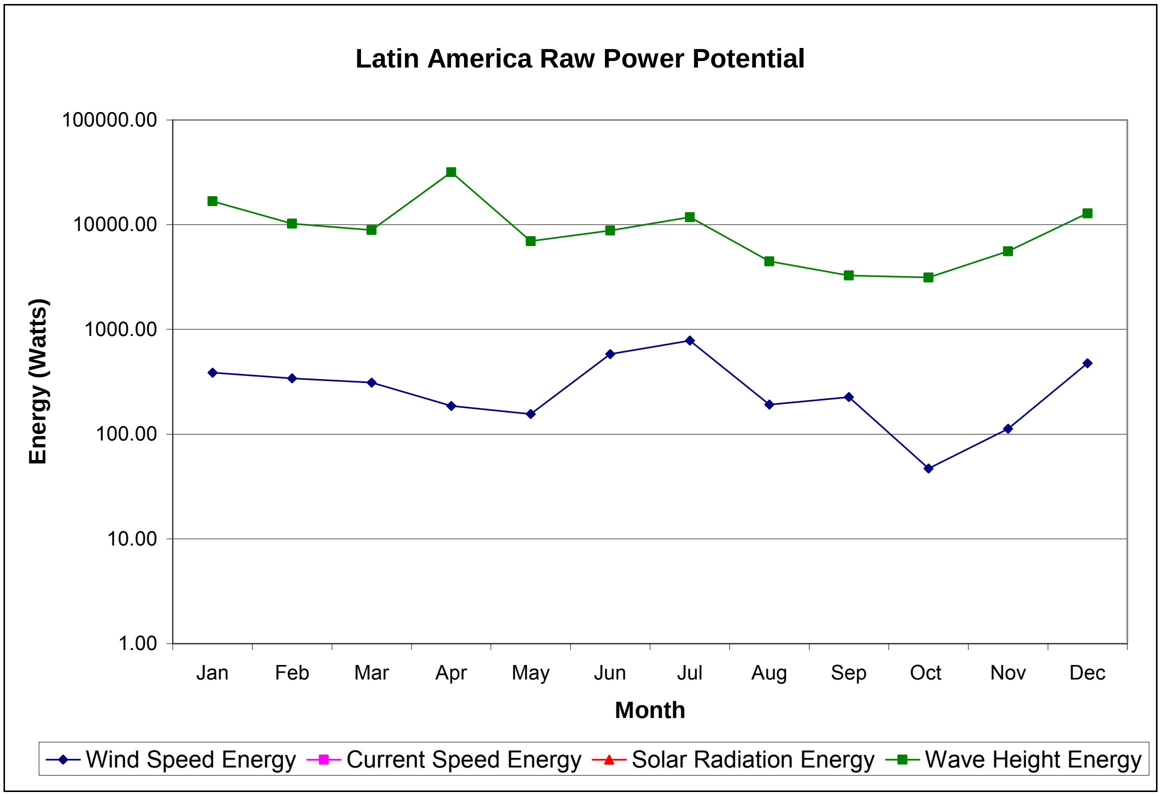
Appendix B. Potential Raw Power

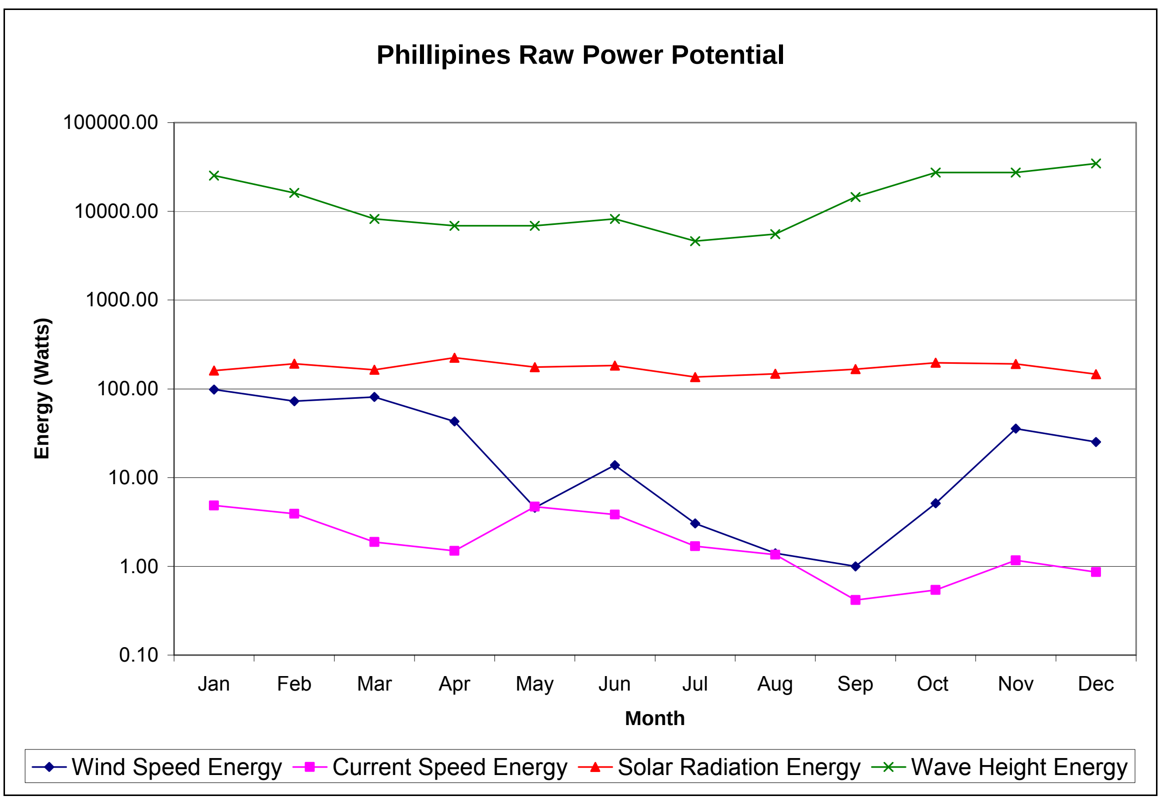


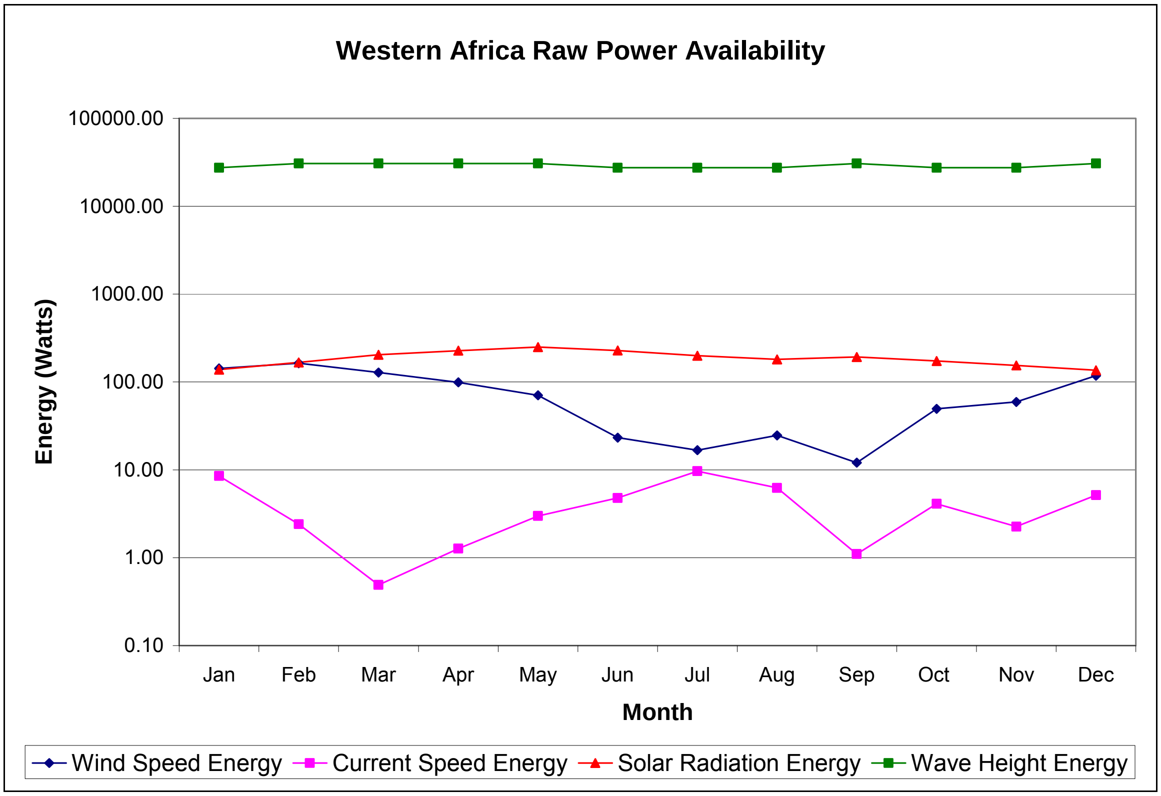



Japan Raw Power Potential
1000.00
100.00
10.00
1.00
0.10
Energy (Watts)
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Month
Wind Speed Energy
Current Speed Energy
Solar Radiation Energy
Wave Height Energy

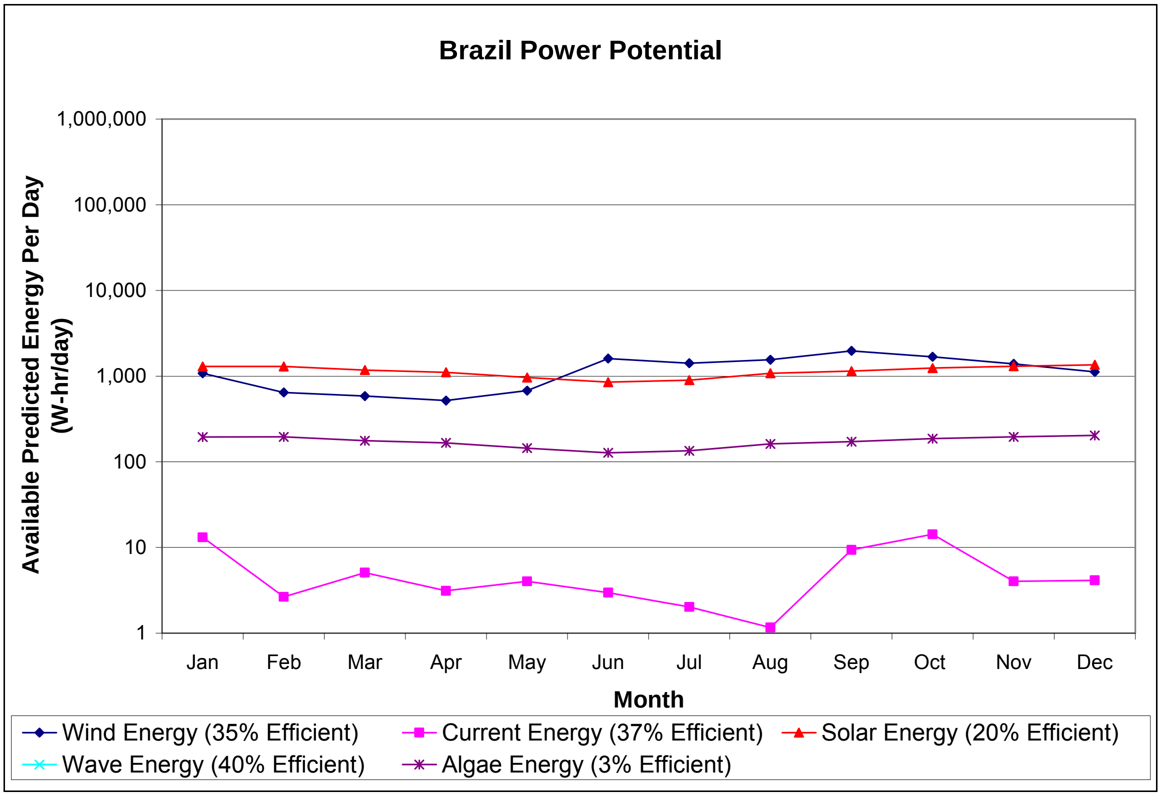

Korea Raw Power Potential
100000.00
10000.00
1000.00
100.00
10.00
1.00
Energy (Watts)
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Month
Wind Speed Energy
Current Speed Energy
Solar Radiation Energy
Wave Height Energy

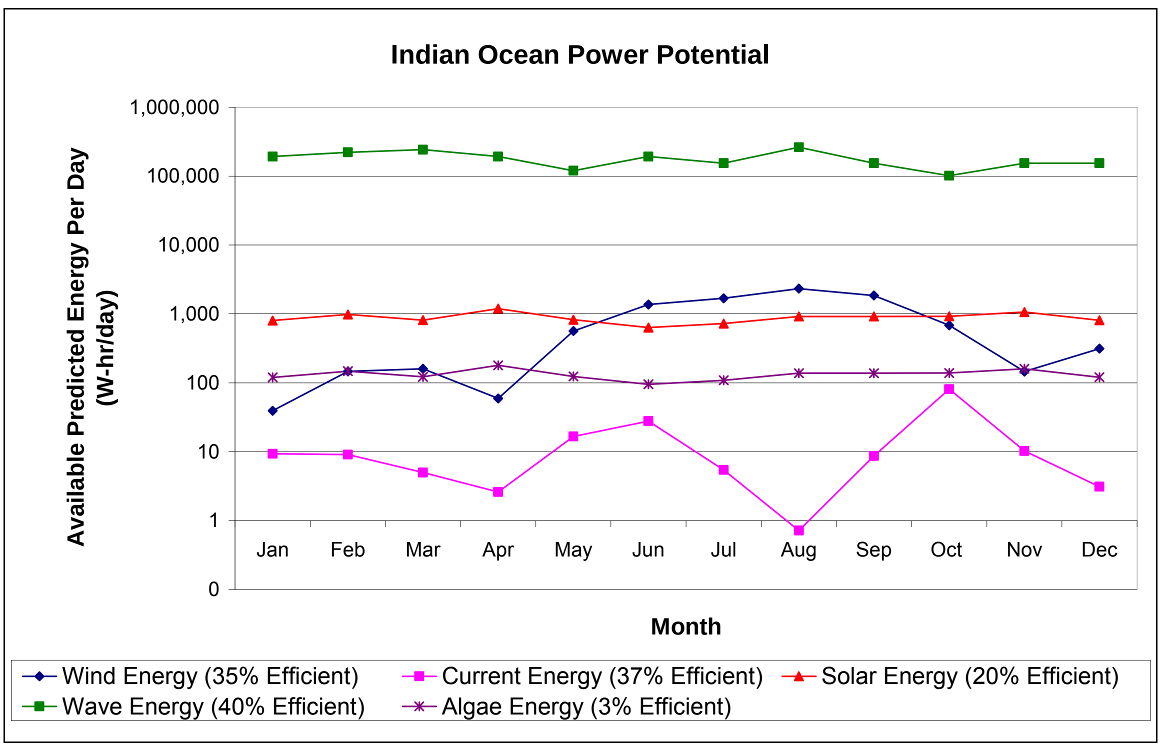

Latin America Raw Power Potential
100000.00
10000.00
1000.00
100.00
10.00
1.00
Energy (Watts)
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Month
Wind Speed Energy
Current Speed Energy
Solar Radiation Energy
Wave Height Energy

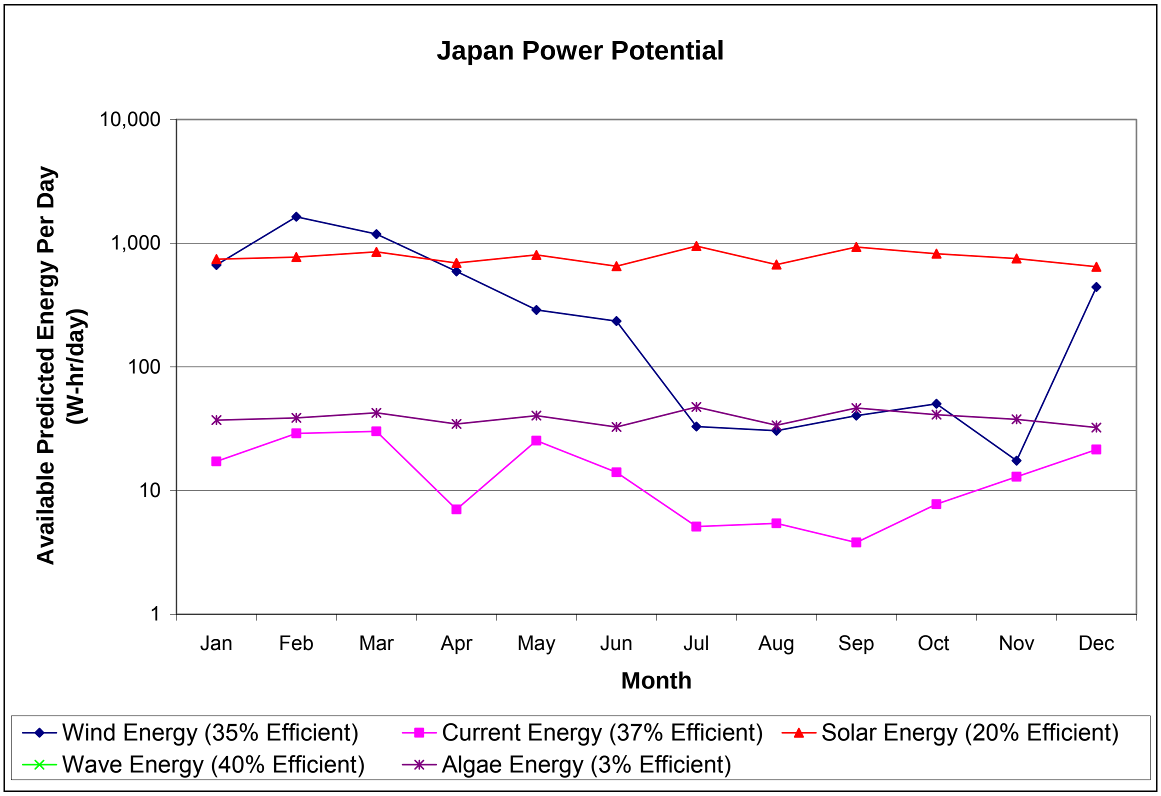

Phillipines Raw Power Potential
100000.00
10000.00
1000.00
100.00
10.00
1.00
0.10
Energy (Watts)
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Month
Wind Speed Energy
Current Speed Energy
Solar Radiation Energy
Wave Height Energy

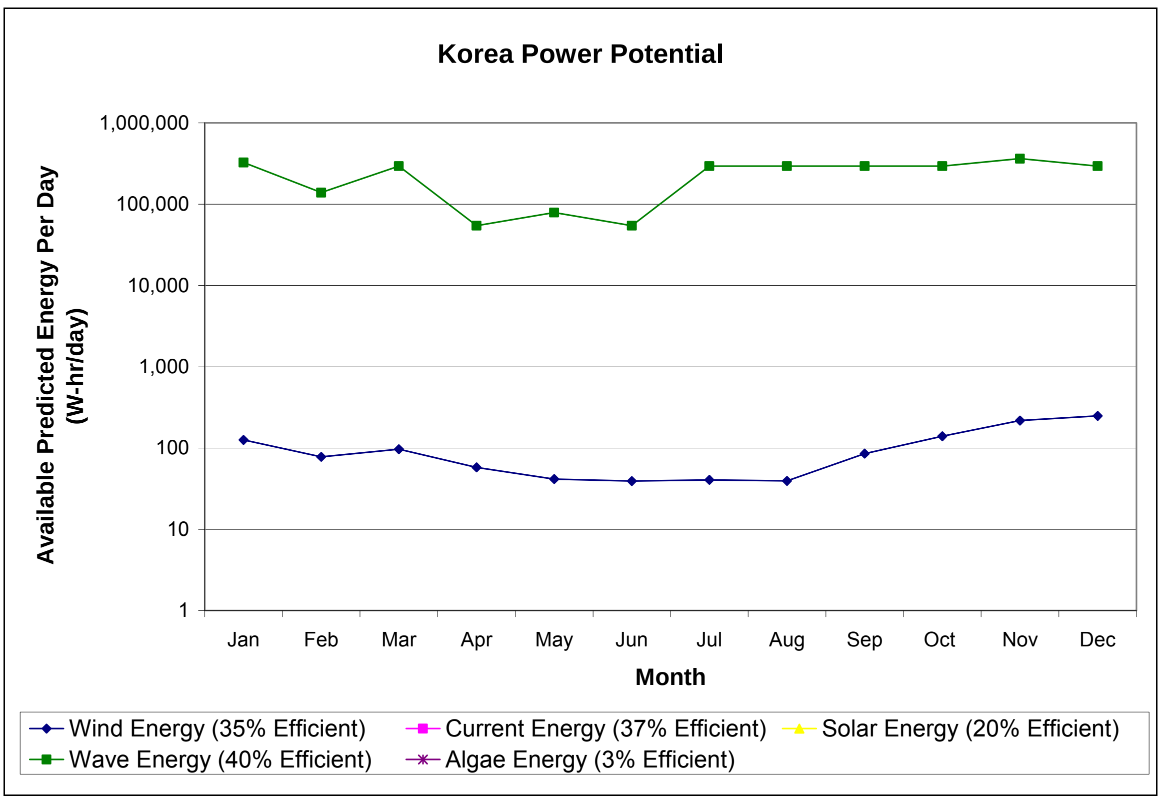

Western Africa Raw Power Availability
100000.00
10000.00
1000.00
100.00
10.00
1.00
0.10
Energy (Watts)
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Month
Wind Speed Energy
Current Speed Energy
Solar Radiation Energy
Wave Height Energy

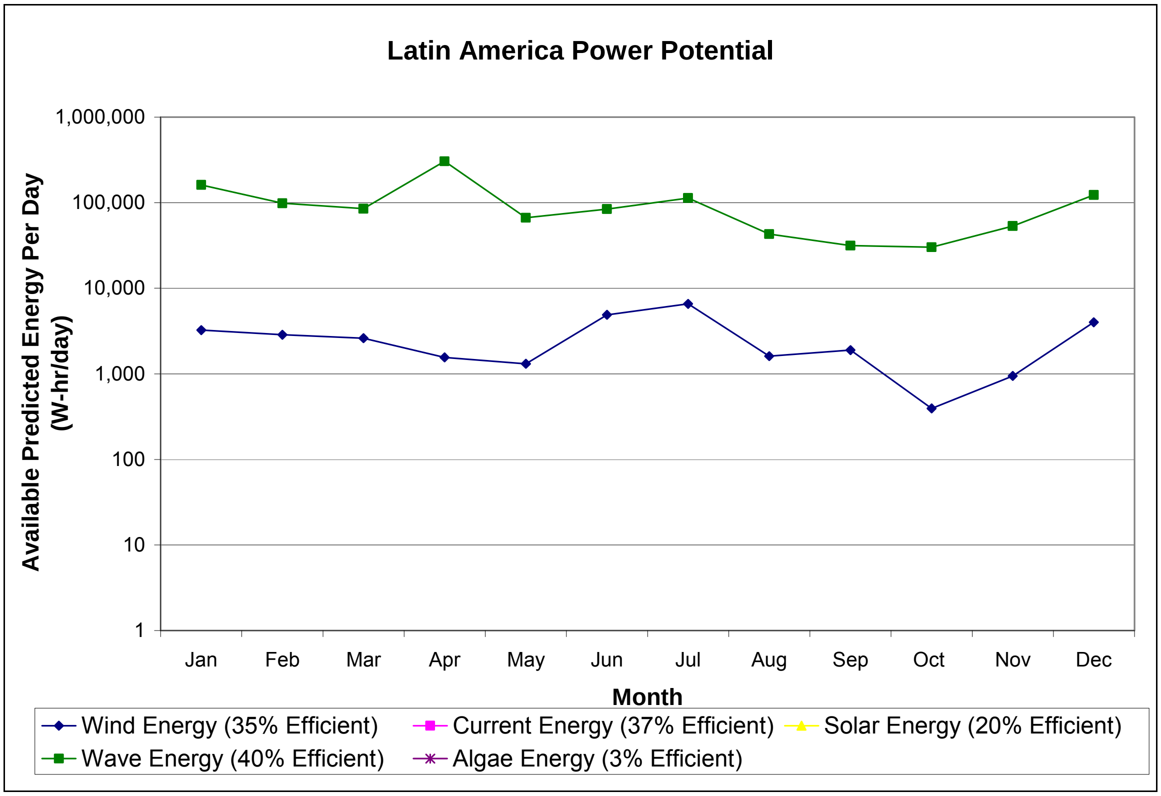
Appendix C. Potential Power Outputs

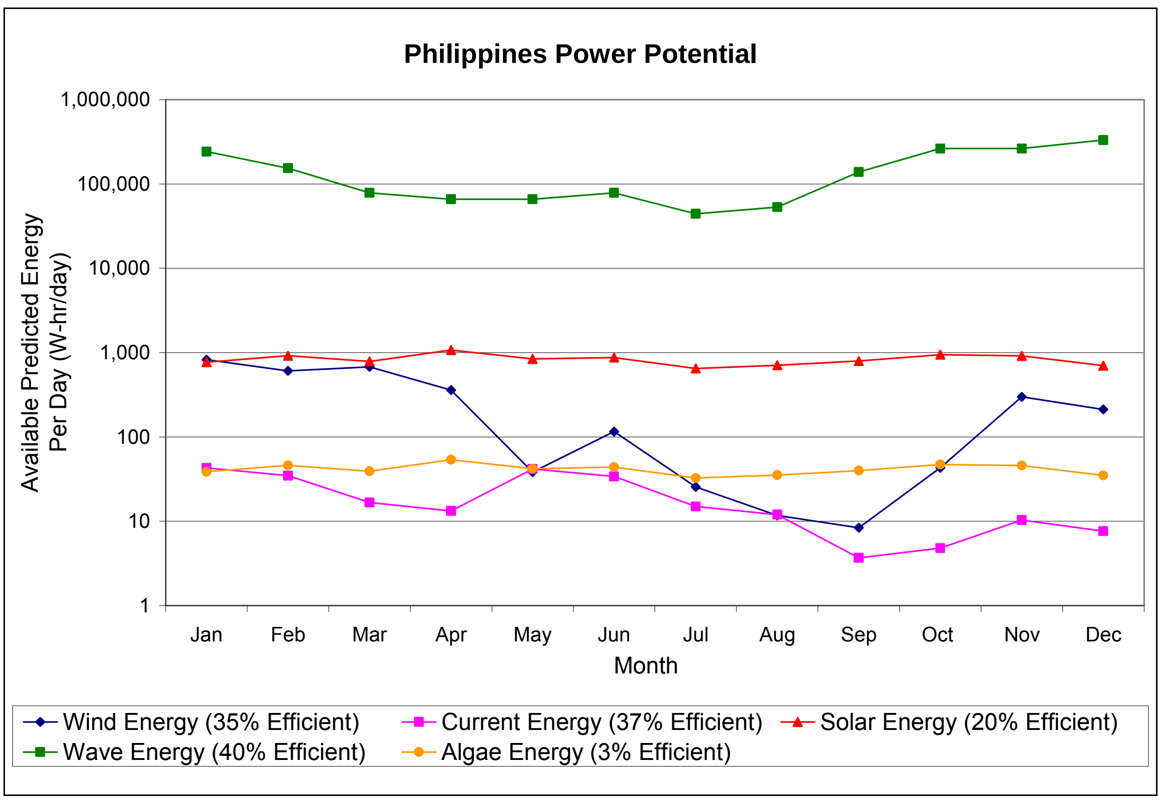


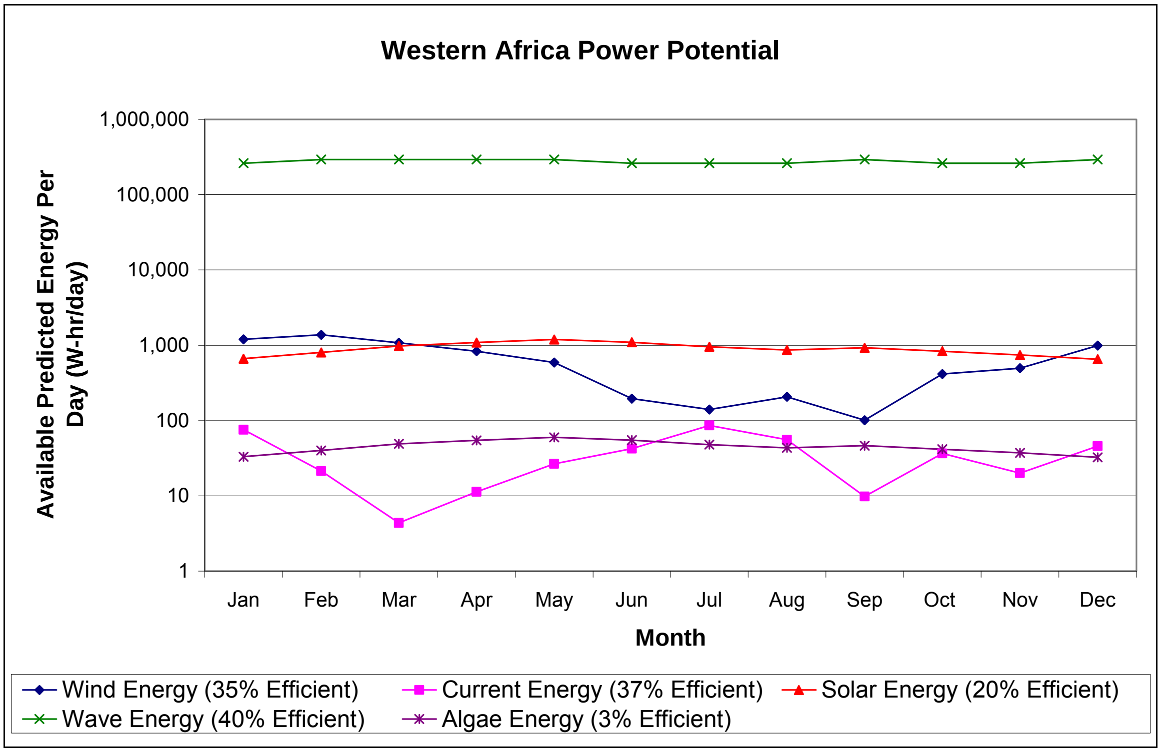



Japan Power Potential
Available Predicted Energy Per Day (W-hr/day)
10,000
1,000
100
10
1
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Month
Wind Energy (35% Efficient)
Current Energy (37% Efficient)
Solar Energy (20% Efficient)
Wave Energy (40% Efficient)
Algae Energy (3% Efficient)

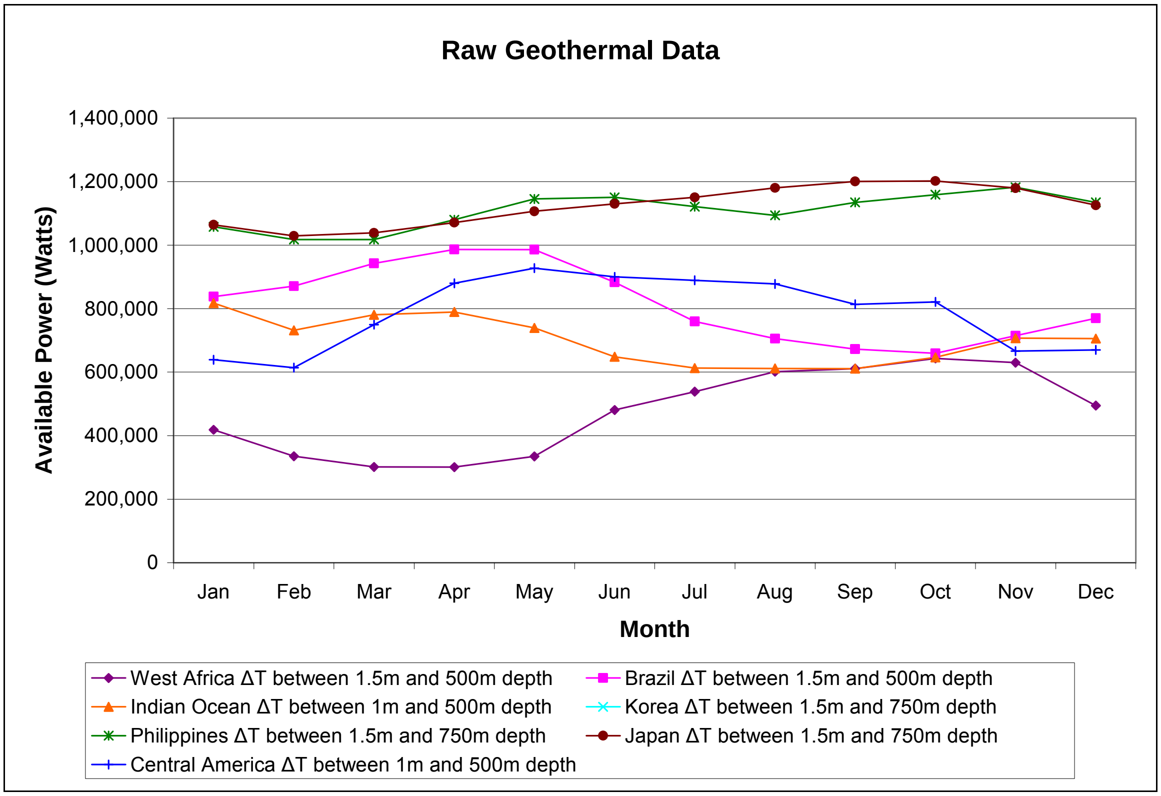

Korea Power Potential
Available Predicted Energy Per Day (W-hr/day)
1,000,000
100,000
10,000
1,000
100
10
1
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Month
Wind Energy (35% Efficient)
Current Energy (37% Efficient)
Solar Energy (20% Efficient)
Wave Energy (40% Efficient)
Algae Energy (3% Efficient)


Latin America Power Potential
Available Predicted Energy Per Day (W-hr/day)
1,000,000
100,000
10,000
1,000
100
10
1
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Month
Wind Energy (35% Efficient)
Current Energy (37% Efficient)
Solar Energy (20% Efficient)
Wave Energy (40% Efficient)
Algae Energy (3% Efficient)

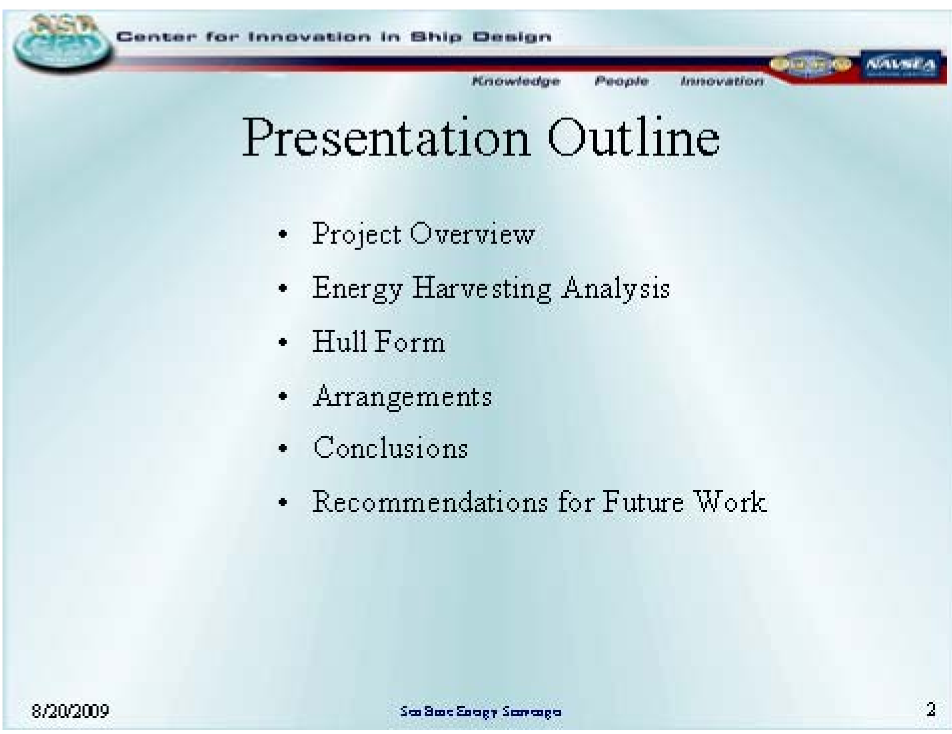

Philippines Power Potential
Available Predicted Energy Per Day (W-hr/day)
1,000,000
100,000
10,000
1,000
100
10
1
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Month
Wind Energy (35% Efficient)
Current Energy (37% Efficient)
Solar Energy (20% Efficient)
Wave Energy (40% Efficient)
Algae Energy (3% Efficient)


Western Africa Power Potential
Available Predicted Energy Per Day (W-hr/day)
1,000,000
100,000
10,000
1,000
100
10
1
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Month
Wind Energy (35% Efficient)
Current Energy (37% Efficient)
Solar Energy (20% Efficient)
Wave Energy (40% Efficient)
Algae Energy (3% Efficient)

Appendix D. Ocean Thermal Power Potential



Appendix E. Ship Integration Study



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Project Overview

- Statement of Necessity
  - Reduce need for energy transport
  - Reduce carbon footprint of Naval sustainment
  - Provide water and/or energy in disaster relief

8/20/2009 Sea Base Energy Scavenger 3

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Project Overview

Objectives

1) Develop a sea basing energy scavenger concept design
2) Report expected ship total expected energy yield
3) Describe challenges and suggest future considerations

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Project Overview

Approach

1) Read and analyze energy scavenging report findings
2) Choose hull form
3) Integrate recommended technologies
4) Estimate expected energy yield

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Energy Harvesting Analysis

Solar Energy

CoolEarth Solar Concentrators™

- Cheap, durable and lightweight plastic material
- 300 to 400 times the concentration of standard PV cells
- 2 meter diameter
- Lightweight and robust support structure
- Up to 0.5 kW power yield

http://www.dailygalaxy.com/

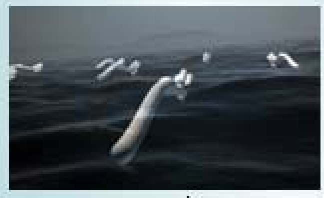
8/20/2009 Sea Base Energy Scavenger 6

Energy Scavenging Analysis
Wave Energy

Anaconda Wave Energy Generator

Checkmate Sea Energy™

- 200 meter LOA
- Rubber material
- Assumed minimal space requirement
- Up to 1 MW power yield



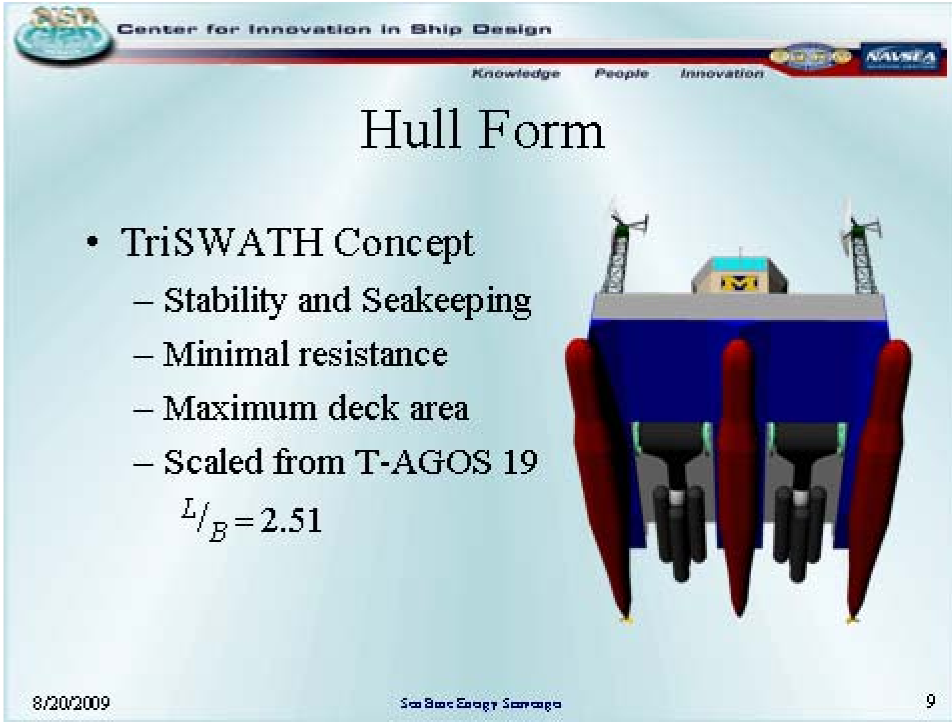
www.popsci.com

Energy Scavenging Analysis
Wind Energy

Helix Wind™ D15000 VAWT

- 41 meter local height (reducible)
- 12 meter rotor diameter
- 12.5 meter blade height
- 150 m^2 swept area
- Up to 50kW power yield

www.helixwind.com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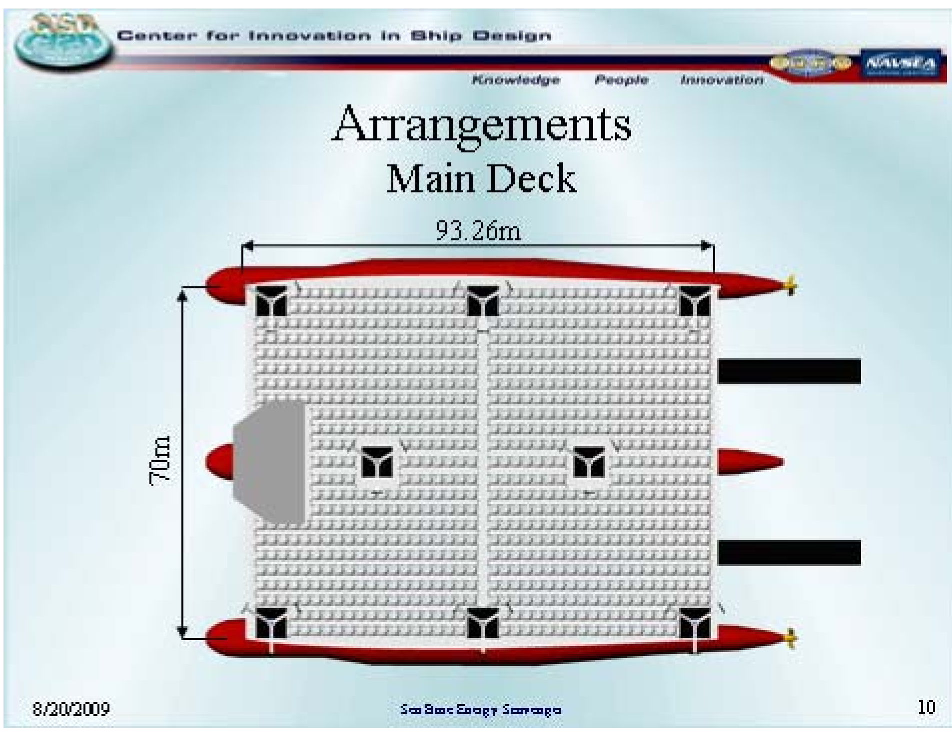
Knowledge People Innovation
NAVSEA
Hull Form
• TriSWATH Concept
– Stability and Seakeeping
– Minimal resistance
– Maximum deck area
– Scaled from T-AGOS 19
$L/B = 2.51$
8/20/2009
9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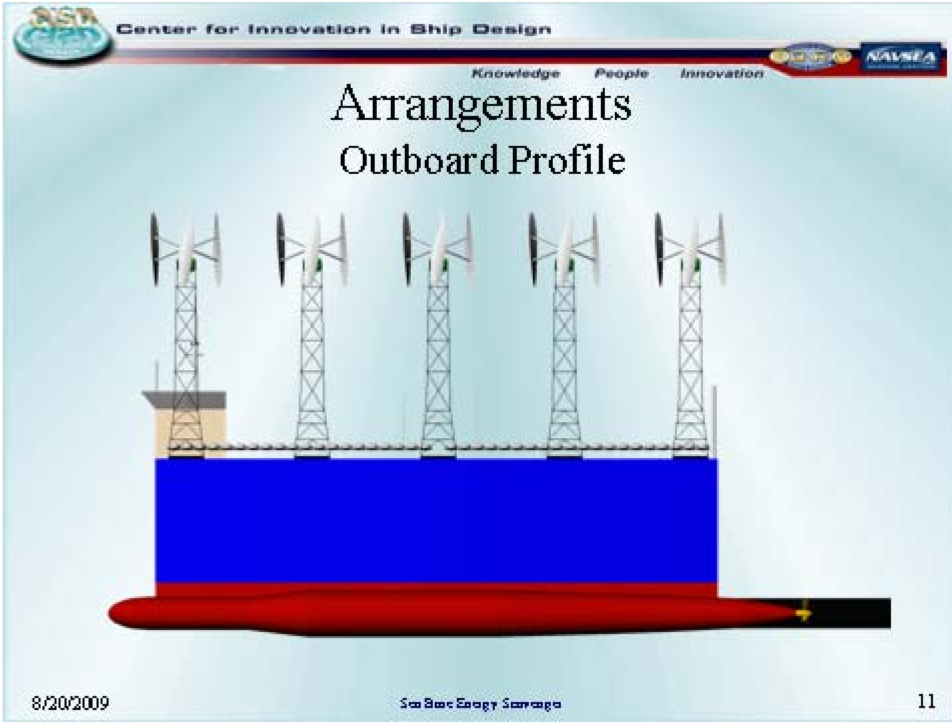
Knowledge People Innovation
NAVSEA
Arrangements
Main Deck
93.26m
70m
8/20/2009
10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Knowledge People Innovation
Arrangements
Outboard Profile
8/20/2009
11


Center for Innovation in Ship Design
Knowledge People Innovation
Arrangements
Inboard Profile
8/20/2009
12

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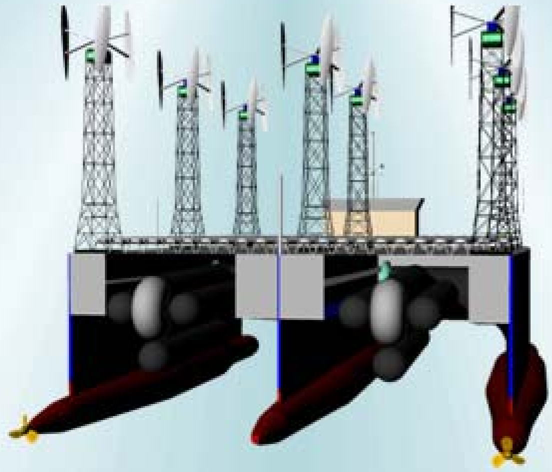
Arrangements

Rear View



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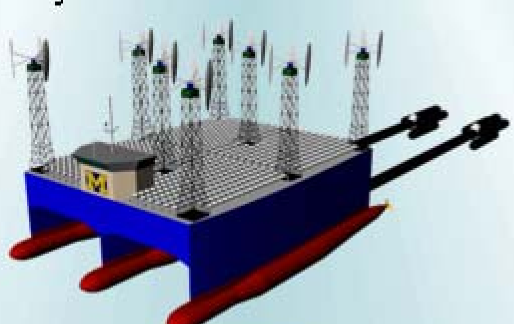
Conclusions

- Conservative energy yield of ~51 MW·hrs/day
- Stable and feasible concept design
- Further analysis needed



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Recommendations for Future Work

- Further research into collection technologies
- Further platform development
- Explore Green ship integration

8/20/2009 Sea Base Energy Scavenger 15

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Acknowledgments

- Jack Offutt
- Dr. Colen Kennell
- Steve Ouimette
- John Stebe
- Hong Yoon Kim
- Maureen Gilmour
- Seth Fireman

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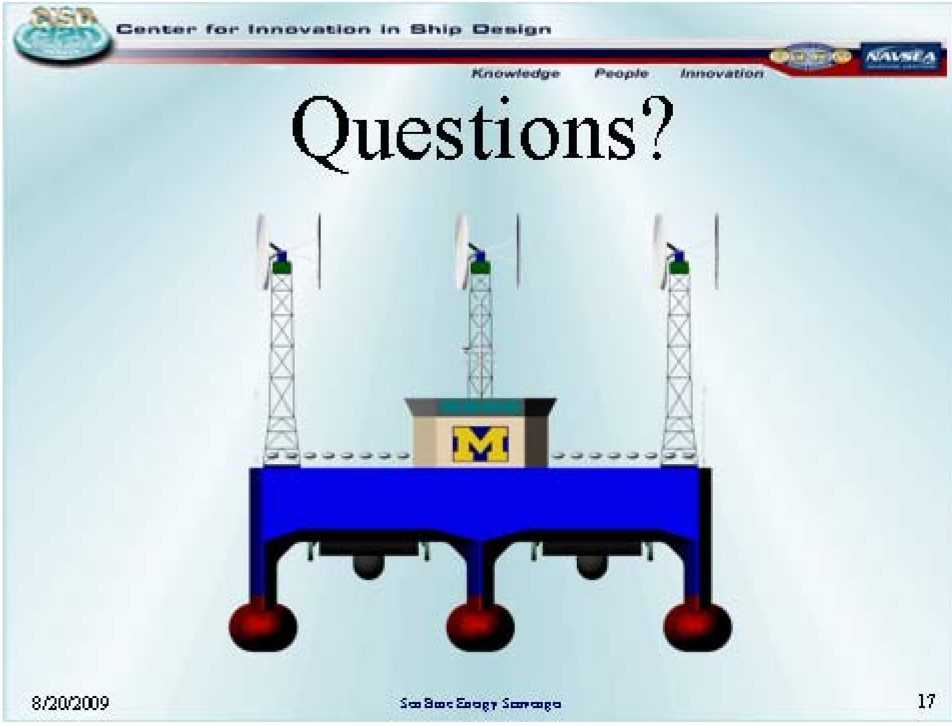
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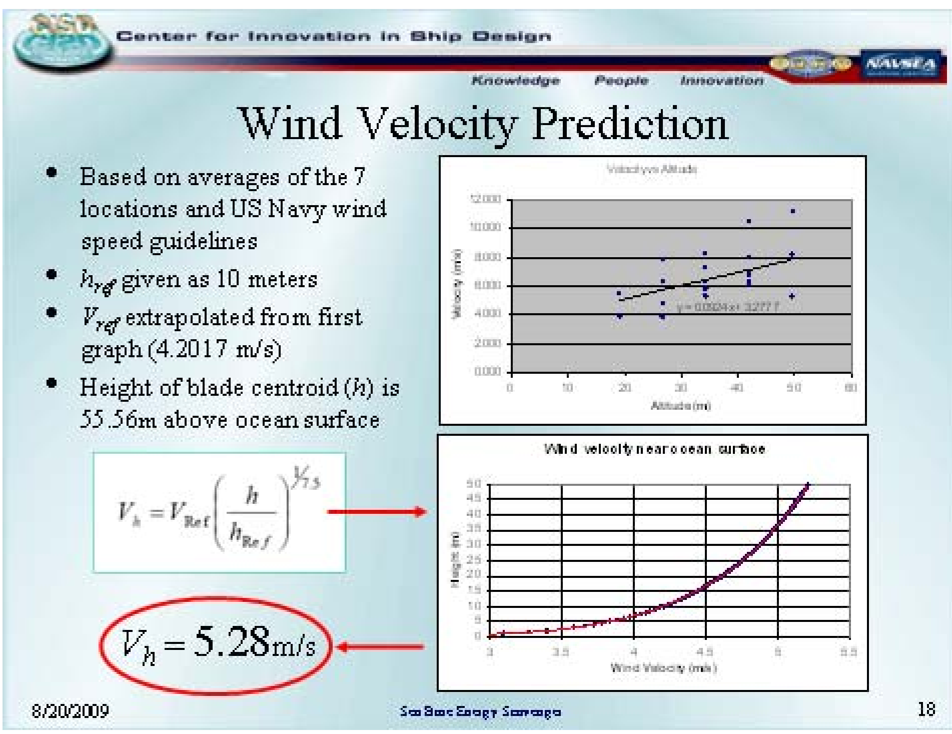
Questions?
8/20/2009
17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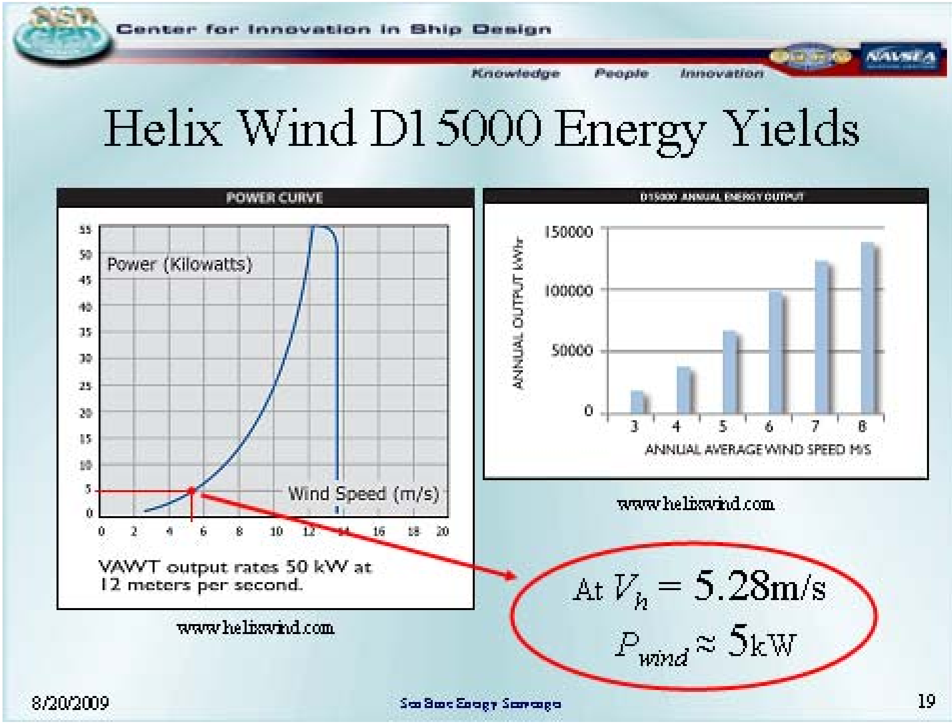
Wind Velocity Prediction
• Based on averages of the 7 locations and US Navy wind speed guidelines
• h_{ref} given as 10 meters
• V_{ref} extrapolated from first graph (4.2017 m/s)
• Height of blade centroid (h) is 55.56m above ocean surface
$V_h = V_{Ref}\left(\frac{h}{h_{Ref}}\right)^{1/7.5}$
$V_h = 5.28$m/s
Velocity (m/s)
Altitude (m)
Wind velocity near ocean surface
Height (m)
Wind Velocity (m/s)
8/20/2009
18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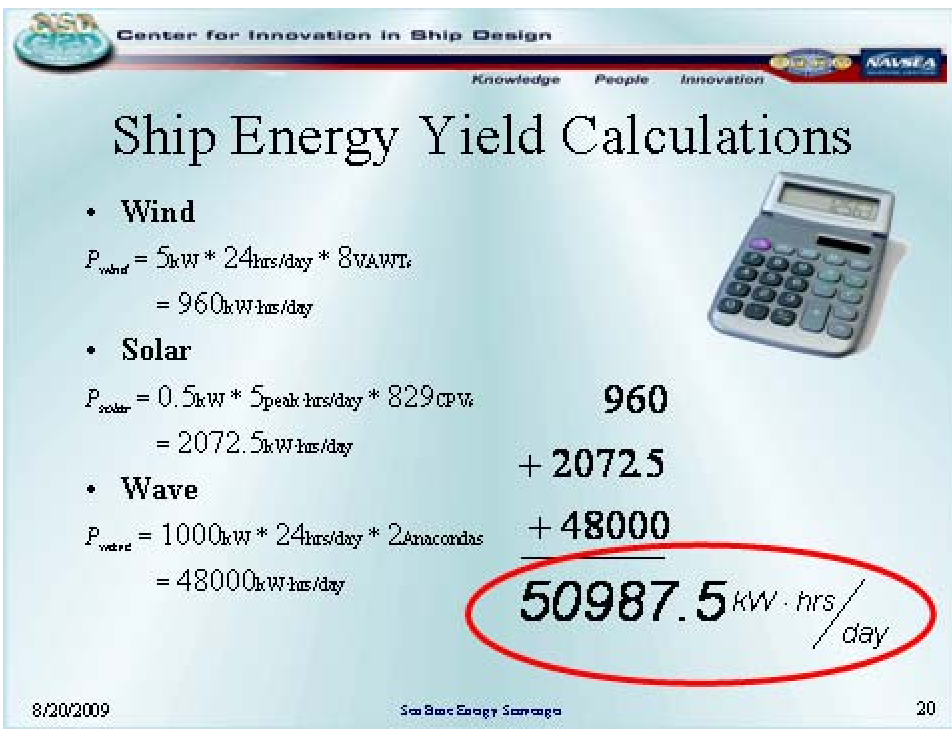
Helix Wind D15000 Energy Yields
POWER CURVE
Power (Kilowatts)
Wind Speed (m/s)
VAWT output rates 50 kW at 12 meters per second.
www.helixwind.com
D15000 ANNUAL ENERGY OUTPUT
ANNUAL OUTPUT kWhr
ANNUAL AVERAGE WIND SPEED M/S
www.helixwind.com
At V_h = 5.28m/s
$P_{wind} \approx$ 5kW
8/20/2009
19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Ship Energy Yield Calculations
• Wind
P_{wind} = 5kW * 24hrs/day * 8VAWTs
= 960kW·hrs/day
• Solar
P_{solar} = 0.5kW * 5peak·hrs/day * 829CPVs
= 2072.5kW·hrs/day
• Wave
P_{wave} = 1000kW * 24hrs/day * 2Anacondas
= 48000kW·hrs/day
960
+ 2072.5
+ 48000
50987.5 kW · hrs/day
8/20/2009
20